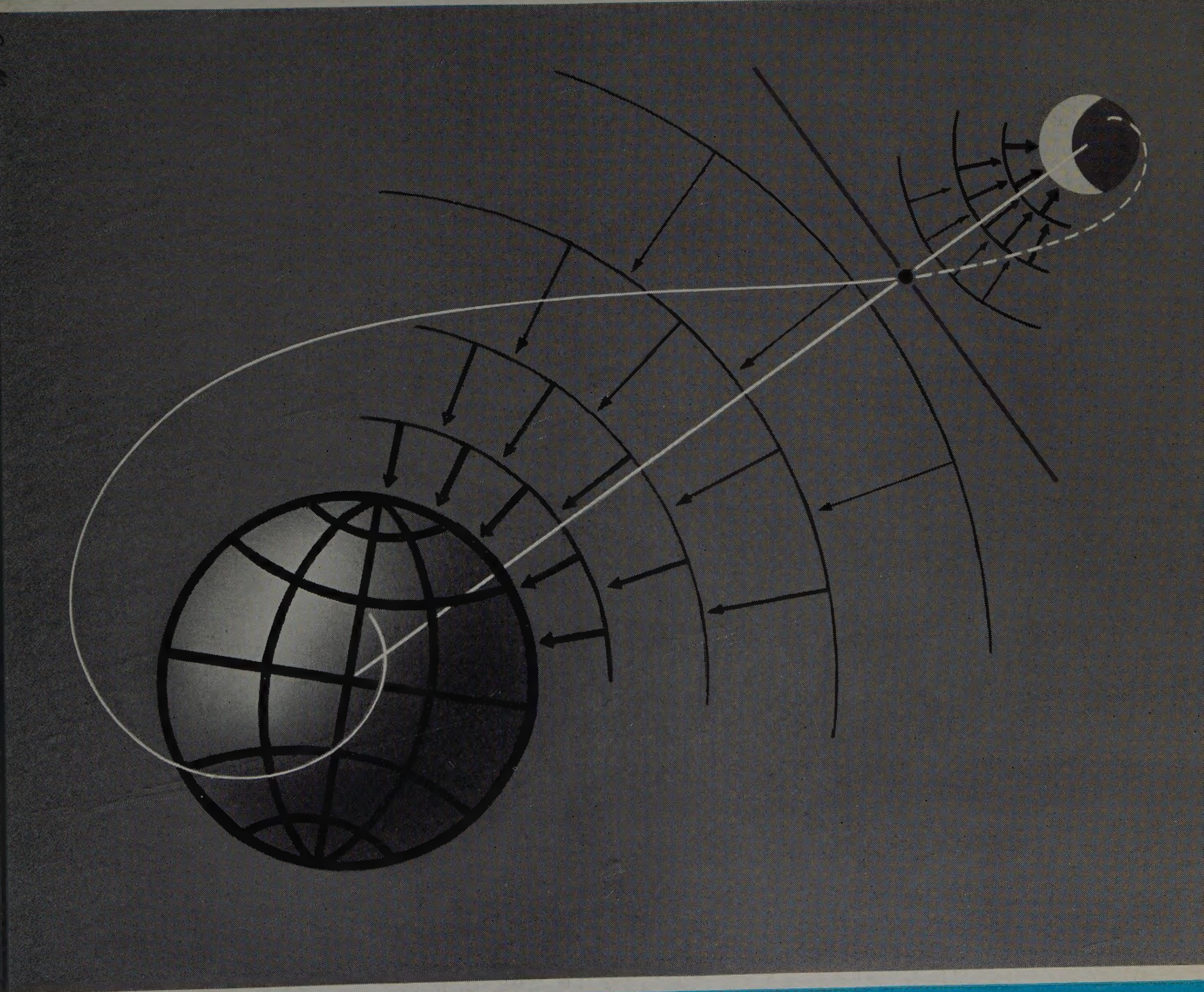
VOLUME V, NO. 2 SUMMER 1958

THE JOURNAL OF THE ASTRONAUTICAL SCIENCES

EDICATED TO THE ADVANCEMENT OF THE ASTRONAUTICAL SCIENCES



INCORPORATING THE ASTRONAUTICAL SCIENCES REVIEW

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■ INCORPORATING THE ASTRONAUTICAL SCIENCES REVIEW

CONTENTS

PUBLISHED QUARTERLY BY

THE AMERICAN ASTRONAUTICAL SOCIETY, INC.

516 FIFTH AVENUE NEW YORK 36, NEW YORK

Printed by the Waverly Press, Inc.

THE AMERICAN ASTRONAUTICAL SOCIETY, INC.

516 Fifth Avenue, New York 36, New York, U.S.A.

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Subscription Rates: One year $5.00; forei $6.00; single copy $1.25. The Journal is pu lished quarterly and sent without charge members of the Society.

Editor, Frederick V. Pohle; *Associate Edito* Allan B. Crunden, Jr.; *Art Editor*, John Quel *Assistant Art Editor*, Alex Ebel; *Advertisi Manager*, Robert Young; *Circulation Manage* George Clark.

Minimum Time Interplanetary Orbits

D. M. Cole*

The Martin Company, Denver Division, Denver 1, Colorado

bstract

Minimum time orbits to the moon and the planets are dis-ssed. The argument is presented that interest will be trans-rred from minimum energy to minimum time orbits when icient nuclear propulsion systems become available.

Results of calculations on continuous thrust travel times to e moon and the planets are discussed for manned and un-anned vehicles.

It is concluded that space flight may take on aspects of onomic utility and such things as extra-terrestrial colonies ay become feasible when these new power sources become ailable.

itroduction

In the early years of space exploration, mission exibility will be severely limited by marginal propul-on capabilities. For reasons of economy and efficiency, rly satellite missions must be carried out with the re minimum in chemical propulsion systems. Missile stems and trajectories must be optimized with heavy nphasis on minimum energy requirements.

The Martin Company has done considerable work on tellite and lunar orbits. Lawden and others have made orough studies of minimum energy interplanetary ansfer orbits. Ref. 1, 2, and 3.

These efforts are essential to the early achievement of tellite and lunar exploration objectives. They may so contribute to the success of the first Mars and enus expeditions. However, we should not assume that ace travel missions will always be energy limited. 'e have only to consider the enormous potential energy cked up in matter and the success which has already en realized in realeasing this energy, to appreciate e possibilities for propulsion systems far superior to r present chemical engines. It is probable that when ich systems become available, emphasis will shift from inimum energy trajectories toward trajectories re-uiring less flight time.

In the history of terrestrial travel we note that early ean crossing explorations were undertaken on a ninimum energy" wind power basis. Later, the higher ergy steam driven systems permitted shorter travel mes. When aircraft became available, it was found to desirable to cut travel times still further even at the st of greatly increased fuel to payload ratios. Com-ercial airlines are now following the military in the xt time reducing step from propeller aircraft to jets, spite of increased propulsion costs.

* Design Engineer

While the primary motivating force in reducing travel times has been the passengers interest in shorter flights, this is not the only factor. Faster vehicles can make more flights per unit time and thus bring greater economic returns. Also, less provision need be made for passenger comfort, sleeping arrangements and food.

Presumably, the same evolutionary process will operate in space travel that has operated in the growth of terrestrial transportation systems. We can expect to see the emphasis shift gradually from the minimum energy orbit to the minimum time orbit as improved propulsion systems become available. It may not be too early to explore, in a general way, some of the problems and consequences of minimum time orbits.

We should remember that although it may be scientists who make the first trip to Mars, it will be the taxpayers who pay for it. While the scientists may not object to spending three or four years on a trip to Mars and, in fact, may welcome such an opportunity, the average taxpayer may be less enthusiastic over the prospect. However, if the taxpayer can be assured that such long travel times represent only the "sailing vessel" era of space flight and that the "steam ship" and even the "jet plane" era will follow soon after, the entire subject of space travel may begin to appear more worthwhile and to take on some aspects of practicality.

It is difficult to equate interplanetary colonization, trade, military operations, or tourist travel with the time, energy, and cost realities of present chemical propulsion systems. However, it is hardly realistic to assume that the trend of technological and scientific progress of the past 300 years will come to a sudden halt. Rather, we should anticipate logarithmic growth in technology, plus occasional major scientific breakthroughs. Anticipating such improvements leads to a picture of future space missions which makes more sense in terms of human factors, economics and military missions at the expense of some loss in technical definition.

Basing space mission calculations on present state-of-the-art, permits accurate detailed design of space vehicles but leads to marginal mission performance and submarginal economic feasibility. State-of-the-art designs give us high assurance of technical feasibility and low assurance of mission feasibility. Extrapolated capability gives us less assurance of technical feasibility, but more assurance of mission feasibility. Both types

of investigation are of value. In this paper we will assume major increases in propulsion performance and consider what effects this improvement may have on mission feasibility in general and flight times in particular.

Minimum Time Orbit, The Brachistochrone

The brachistochrone is the path between two points requiring the shortest transit time. In this paper we will be concerned with brachistochrones for continuous thrust rockets moving in inverse square central force fields for both high and low thrust-to-field force ratios. Before attempting to determine the brachistochrones for these cases, consideration of a simple example may be in order.

Consider an object sliding on a frictionless surface near the earth's surface. What is the curve along which the object must be constrained to descend under the influence of gravity in order to pass from one point to another in the shortest possible time? It is assumed that the gravitational field is uniform and perpendicular to a flat earth.

From this simple set of assumptions, one can proceed through some not-so-simple mathematics (Ref. 4) to a simple solution. The curve is a cycloid with a vertical axis. Figure 1. Note that in this special case the constraining force varies in direction and magnitude throughout the trip. The direction of the force is always perpendicular to the path and the constraining force is equal and opposite to the component of gravity along this perpendicular. Note also, that this is a very simple physical situation; the answer to the problem is simple and neat, but the derivation of the equation and the proof that the curve is, indeed, the brachistochrone, are not so simple.

In the case of the interplanetary transfer orbit, we have also a fairly simple physical situation. By analogy with the flat earth constant field case we can hope for a simple answer, but also by analogy we can expect some complexity in the derivation and proof.

In the interplanetary case, we have an inverse square central force field rather than a constant uniform field. We do not know initially how the constrained force vector (the engine thrust) will vary and we have initial and final orbital velocities to consider. In the general rocket case we must also contend with a varying mass.

Perhaps the greatest problem in determining the interplanetary brachistochrone is that of the varying thrust vector. Separate cases can be considered for different thrust magnitudes and durations. For simplicity, the thrust may be considered an impulse of zero duration or it may be assumed constant throughout the flight. These approximate realistic situations. The problem of directional variation cannot be handled so simply however. Should the direction be constant? Should the thrust be directed outward along a radius from the center of force? Should it always be perpendicular to a radius? Should it be constantly along the flight path, or should it vary as some unknown function of the velocity, position, and thrust-to-field force ratio? Unfortunately, the later case appears to be correct. As will be seen below, none of the other alternatives will satisfy all cases.

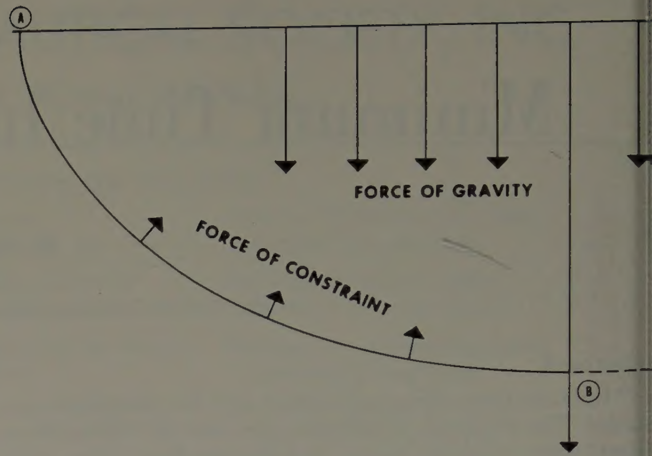

Fig. 1. Cycloid with Vertical Axis

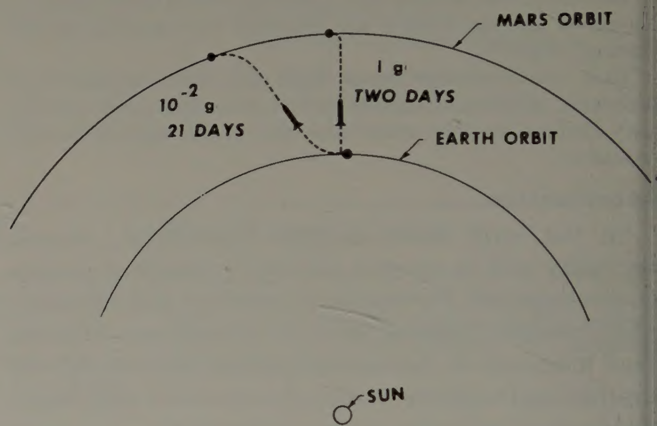

Fig. 2. Earth-Mars Constant High-Acceleration Orbits

Continuous Acceleration

A. High thrust-to-field force ratio.

1) Constant acceleration.

For simplicity the case considered will be one of constant acceleration where the field force is low compared to the thrust. Constant thrust acceleration may be achieved by reducing thrust at the same rate as the vehicle mass is reduced (due to consumption of propellant) or by using a constant thrust and a propulsion system of such high performance that the change in mass is negligible.

It is assumed that the thrust acceleration is at least ten times the field force acceleration. This would be true for interplanetary vehicles at large distances from the earth with thrust accelerations of at least 10^{-2} g's. (The acceleration due to the sun's gravity at the earth's orbit is 6×10^{-4} g's.) It would also be true for vehicles leaving earth with thrust accelerations of 10 g's.

An example fitting the above assumptions is a trip from the orbit of the earth to that of Mars, with con-

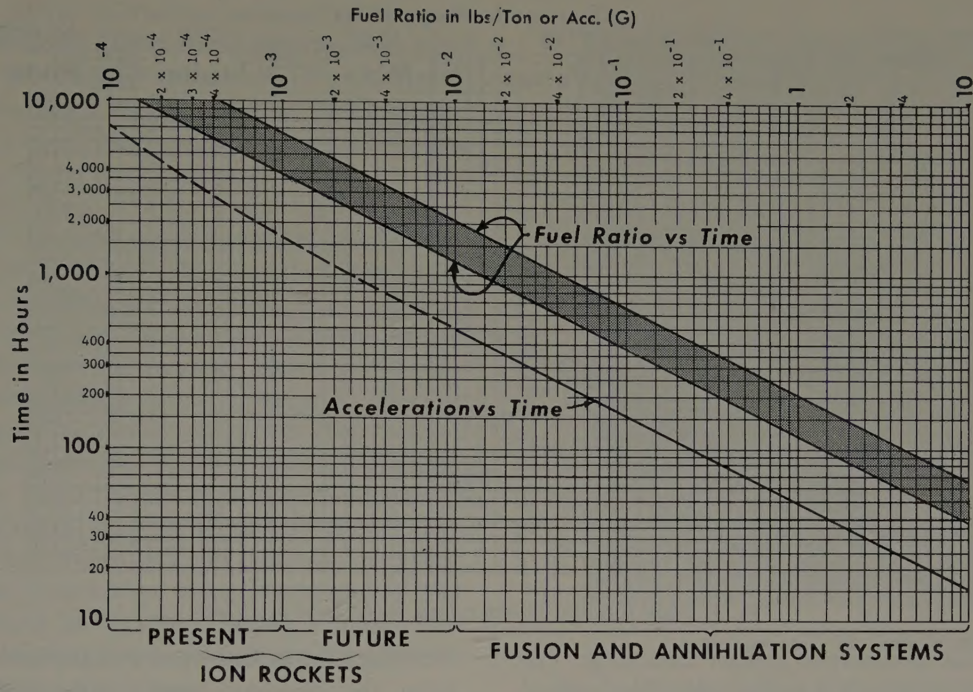

FIG. 3. Earth-Mars Inter-orbit trip

tant thrust acceleration of more than 10^{-2} g's and nidpoint turn around. Reference 5. The travel times nvolved are so short that angular motion is small and he flight path is almost directly out along the radius ector from the sun for most of the trip. Consequently, he short arcs of the two orbits can be approximated by traight lines. It can be demonstrated easily that for this pproximation the thrust vector should be constantly erpendicular to the orbits or along the radius vector o the sun. Figure 2.

Suppose that in the 1 g case (Figure 2), the thrust had een oriented along the flight path instead of along the adius vector. The initial flight path is tangent to the arth's orbit. Since the sun's gravity is negligible, the light path would remain along this line and thus the ehicle must travel about 106 million miles instead of 9 million miles along a radius. This trip would take hree days as compared to two days for the radial trip.

Assuming that the thrust is oriented along the radius ector, the brachistochrone is a symmetrical S-shaped

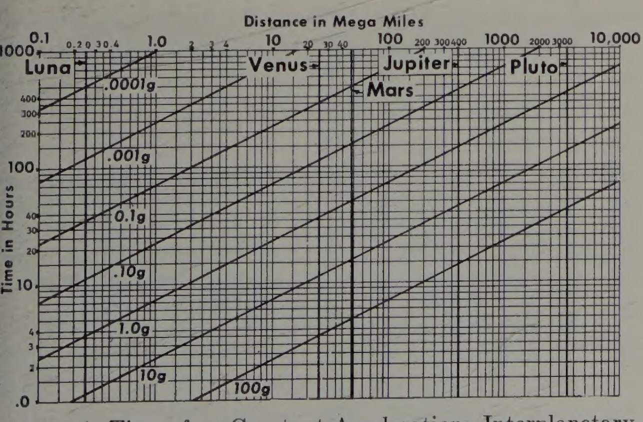

FIG. 4. Time for Constant-Acceleration Interplanetary rips with Midpoint Turn Around.

parabolic curve tangent to the two planetary orbits and asymptotic to the orbit radius.

Times of flight for the "high thrust" earth-Mars brachistochrone are shown on Figure 3. Also shown on Figure 3 are the amounts of deuterium required for such trips, assuming theoretical conversion of fusion energy to propulsion.

Times of flight for "high thrust" trips to other points in the solar system are shown on Figures 4 and 5. Figure 4 is based on an assumption of mid-point turn-around and deceleration. Figure 5 is based on acceleration all the way to the "target." The destination point would be a "target" since a military warhead is the most likely passenger for a non-decelerating rocket.

2) Variable acceleration.

Another example of a high thrust system which has been considered (Ref. 6) is the earth-moon trip. It is assumed that initial thrust will be high enough to make the radial flight path the brachistochrone. This should be true for initial thrust acceleration of 10 g's or more. It is assumed that the boost phase will last for a very short time to minimize crew discomfort, after which a constant 1 g thrust acceleration will be sustained for the remainder of the trip. Figure 6 shows times for earth-moon trips using the above thrust programming. Total trip times and boost phase times are shown as functions of boost acceleration. The duration of the boost phase decreases as the magnitude of the acceleration increases, to reduce the strain on the crew.

Note that the total trip time varies only slightly with boost acceleration ranging from about three hours to about three hours and 15 minutes.

The radial flight path should be the brachistochrone

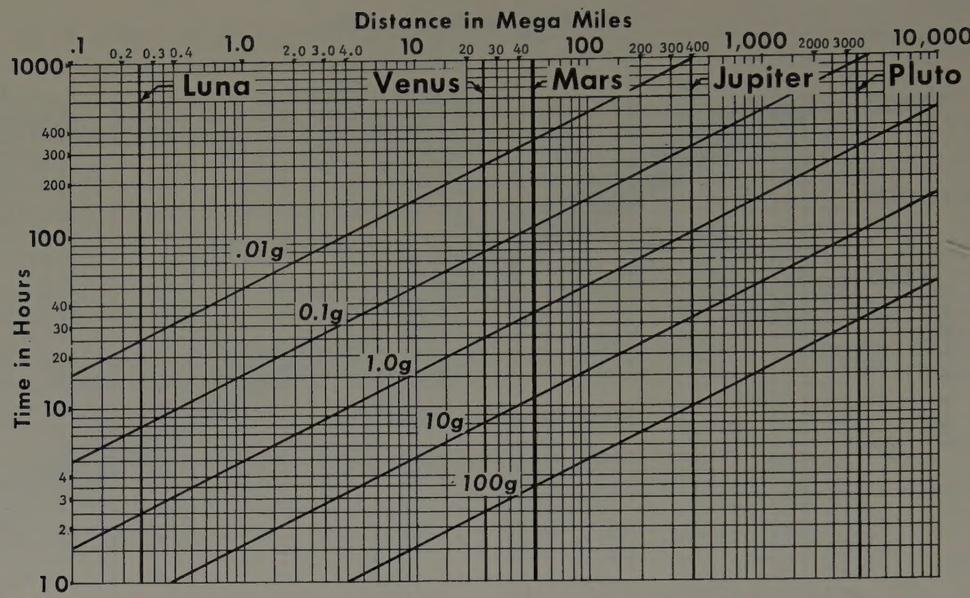

Fig. 5. Time for Non-Decelerating Interplanetary Trips

for values of boost acceleration greater than 10'gs. For lower values, some inclination to the radius (or vertical) would be advisable for the boost phase.

If a fusion system were used for this trip, from three to nine pounds of deuterium would be required to propel a 100 ton vehicle. This assumes complete conversion of fusion energy to propulsion. Only one one-hundredth of one pound of matter would be annihilated.

The time required to complete the 1 g sustainer portion of the flight (from boost to turn around) is given by

$$t = 19.1\,[4.09 - \sqrt{S} + \tan^{-1}\sqrt{S}]\text{ minutes}$$

where S is the distance in earth radii from the center of the earth to the beginning of the sustainer phase. Time for the deceleration phase is always 108 minutes since position and velocity at the beginning of this phase are always the same. The time for the boost phase can be calculated with reasonable accuracy by assuming a constant net acceleration, since the thrust is large relative to the field force.

B. Low Thrust to Field Force Ratio

In this category are included all cases where thrust acceleration is less than ten times the field force acceleration. The extreme example of this category is the zero thrust case, in which the space ship travels in a Keplerian ellipse about the sun (or the earth).

Some work has been done on very low thrust systems by Stuhlinger and others, References 7 and 8, with emphasis on minimizing energy, as has been the case throughout classical astronautics. However, if thrust is constant throughout the journey, energy expenditure is a direct function of the time of travel and the minimum energy path is also the brachistochrone. In the high thrust cases it was apparent that there was more energy available than the minimum required to get the payload to its destination. This is not apparent in the very low thrust cases. Unless special attention is paid to reducing time at the expense of payload to gross weight ratio, the minimum energy curve and the brachistochrone will be the same path. In this paper, of course, the intention is to emphasize the case where there is a surplus of available energy over the minimum required for the mission.

If the thrust is low but available energy exceeds that required for the minimum energy orbital transfer, how should the thrust vector be oriented? If not directed in the same direction throughout the flight, how should the change in direction be programmed? For the high thrust cases it is clear that the thrust vector should be outward along the radius vector. Is this also true for low thrust cases?

A simple example of the low thrust case is that where the rocket is initially at an arbitrarily large distance from an attracting mass at zero initial velocity with a capability for producing thrust just equal to the field force at the starting point. The objective is to reach a higher orbit in minimum time. The distance to the target orbit is a contributing factor and initially will be considered as of the same order as the distance to the attracting mass.

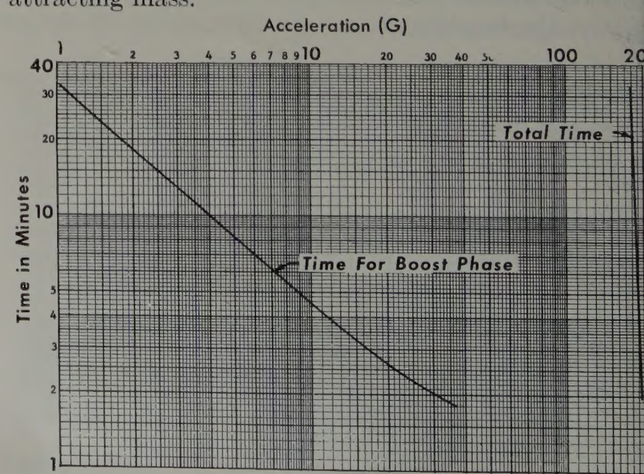

Fig. 6. Time for Variable Acceleration-Earth-Moon Flight

If the thrust vector is oriented outward along a radius, as was done in the high thrust cases, it is clear that no motion will result. The rocket will be in unstable equilibrium under the action of the equal and opposite thrust and field forces. This is apparently a poor choice. What, then, should be the thrust orientation?

One method of approach to this problem is to consider which initial orientation will produce mechanical energy at the greatest rate. Since the rocket is consuming energy at a constant rate, regardless of orientation, the orientation resulting in the greatest rate of energy production should give the greatest efficiency.

For all but the equilibrium case where no mechanical energy is produced, potential energy will decrease and Kinetic energy will increase. It can be shown that for all orientations the rate of increase of Kinetic energy is exactly twice the rate of decrease of potential energy. It is found that the net rate of increase increases from zero for the vertical orientation to a maximum at the radially downward orientation. Figure 7 shows the rate of increase in energy as a function of angle between the thrust vector and the radius.

This indicates that the most efficient initial orientation is straight down toward the attracting mass!

Obviously, this orientation if used at all, could not be maintained for long or a collision with the attracting body would become inevitable. If the rocket is to reach its destination, it must pull out of its dive and curve out beyond its initial orbit. This is a special case of the classical "gravity well" maneuver. It indicates that the best path for a rocket launched from rest at the surface of the earth is straight down through the center of the earth. Unfortunately, some test rockets seem to take this reasoning seriously and try to follow this maximum efficiency path!

Although the initial downward orientation appears to be the most efficient for the rocket starting from rest, it will not necessarily produce the brachistochrone. This depends on the time required for the gravity well maneuver as related to the distance to the destination, and the magnitude of the field force gradient.

Now assume that the rocket has an initial horizontal velocity of magnitude and direction required for a stable circular orbit. Is it desirable to point the thrust vector outward as in the high thrust case, or inward as in the low thrust zero initial velocity case?

In approaching this problem it may be useful to ignore the attractive force for a moment and consider the rocket to be traveling at a constant speed in a straight line. Now let the thrust be applied at right angles to the motion. The rocket path will be bent into an arc of radius, r, where MV^2/r = thrust. If the thrust is held perpendicular to the path, the rocket will revolve in a circular orbit. Here is a second case where the engines are consuming energy but no mechanical energy is being produced.

This example illustrates that when thrust is applied at some angle to the flight path, the component of the thrust at right angles to the flight path does not contribute to increasing the Kinetic energy of the rocket!

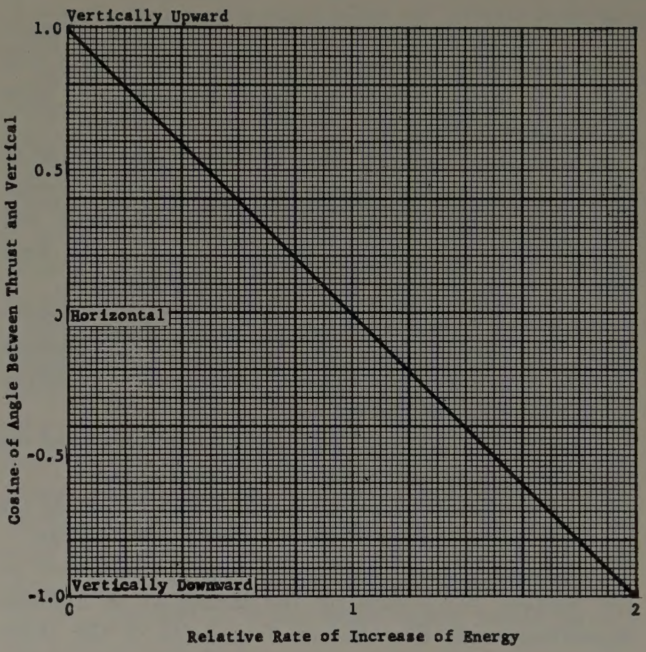

Fig. 7. Relation of Rate of Energy Production to Orientation of Thrust Vector

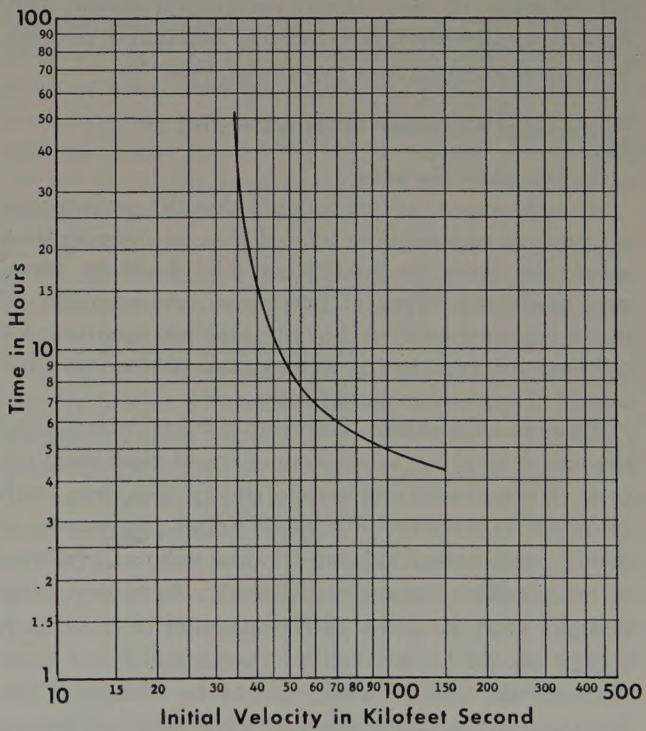

Fig. 8. Time for Impulse Thrust Flight to the Moon

Returning now to the rocket in its stable circular orbit about an attracting mass, it is noted that thrust applied along the flight path will make the maximum contribution to increasing Kinetic energy. Thrust applied at angles below the flight path will reduce potential energy and produce less than the maximum Kinetic energy. Consequently, this operation would be undesirable. Thrust directed above the flight path will not give the maximum increase in Kinetic energy but will

produce potential energy. If the destination is a higher orbit, then thrust directed above the flight path will move the rocket closer to its destination and thus reduce flight time.

It appears, therefore, that a thrust orientation at some angle above the flight path is optimum for a rocket leaving a stable circular orbit. The exact angle will depend upon the thrust to field force ratio, the field force gradient, and the distance to the destination.

In summarizing what has been said on thrust orientations for initiating minimum time orbits for constant thrust, constant mass rockets, some general observations might be considered.

1. In high thrust cases emphasis should be placed on minimizing distance traveled to the destination.

2. In low thrust cases emphasis should be placed on maximizing the rate of increase of mechanical energy.

3. Energy is dissipated in opposing the field force or the rockets momentum by the thrust to an amount depending upon the relative magnitude of the three quantities.

4. For low thrusts, distant objectives and initial vertical velocities of zero, thrust orientation should vary from vertically downward for zero horizontal velocity, to horizontal for circular horizontal velocity.

Propulsion Systems—Figures 9 and 10

A. Chemical Rockets

It might appear at first thought that the performance of chemical rockets is so limited that no consideration should be given to minimizing interplanetary travel time until new types of propulsion are available. It might be assumed that the only practical approach for the near future is to try to maximize payload to gross weight or payload to energy ratio.

There is no question, however, that some consideration must be given to shortening travel time since the time for an absolute minimum energy trip from earth to moon is infinity, Figure 8. Small increments of velocity above the minimum required reduce travel time to reasonable values. Obviously, therefore, some thought must be given to the question of how much energy should be devoted to shortening travel time. Some of the factors which should be considered are discussed in the next section. Very large reductions could be made below the two to four day earth-moon travel times usually contemplated, if the reduction was considered worth the cost.

For example, suppose that a rocket capable of achieving satellite velocity is lifted to a minimum orbit before firing. The rocket can then achieve a burnout velocity over 50,000′/sec and will reach the moon in less than nine hours! Figure 8.

However, to achieve short travel times with chemical rockets, gross weight to payload ratios must be enormous and major reductions in time at reasonable cost must wait for advanced systems.

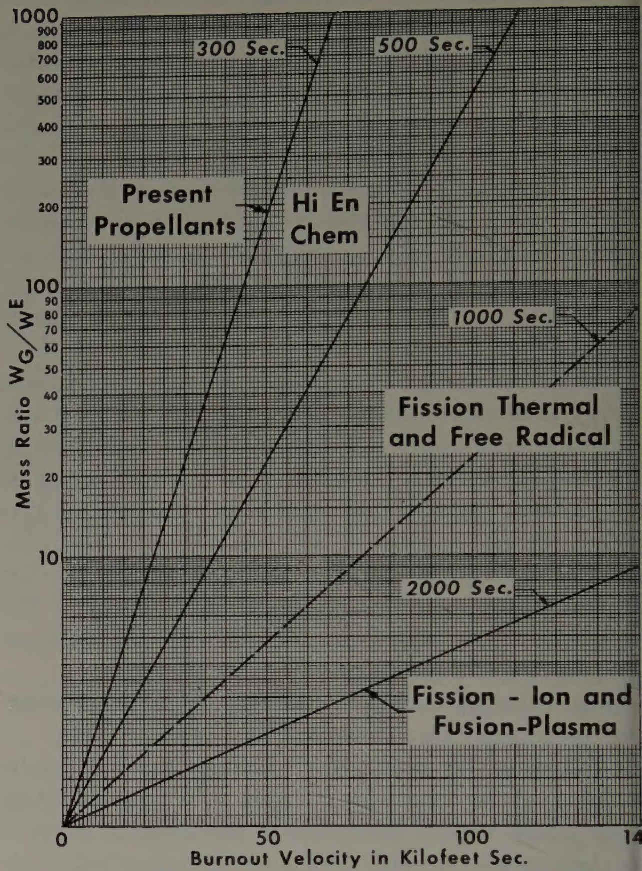

Fig. 9. Performance of Advanced Propulsion Systems

B. Nuclear Rockets

When nuclear reactors are used to heat a workin fluid which is then expelled from a nozzle in a manne similar to the liquid chemical rocket, performance i limited by the maximum temperature that can be tol erated in the reactor. Although performance may b superior to that of chemical rockets, systems publi cized to date do not offer great hope of high g, con tinuous acceleration Mars rockets. Fortunately, how ever, there are several possible methods of solving thi temperature problem.

One method which has received considerable atten tion recently is to use the nuclear reactor to generat electricity and then use electrically accelerated charge particles to provide thrust. Such systems will provid continuous thrust for long periods, but thrust-to-mas ratios are low—on the order of 10^{-4} g's. Undoubtedly methods will be discovered for reducing the weights c these propulsion systems and thus increasing accelera tions. If a single nuclear reactor could be used to heat working fluid, as in a "conventional" nuclear rocke and then used in an ion accelerating system, significan gains in performance might be realized. The high thrus thermal rocket would be used in the beginning of th flight to overcome the earth's gravity, then the lo thrust ion engine would be used as a sustainer to shorte travel time. Some of the shielding required for the io system, could be replaced by propellant (which would b used for shielding) with a resulting improvement i performance.

The fusion reactor looks more promising as an even-
ual basis for the high continuous thrust system. It
nay be possible to eject a high speed plasma directly
rom the fusion reactor, eliminating the heavy inter-
nediate equipment of present ion rocket designs.

The "ultimate" rocket from the point of view of our
oresent ignorance, is the matter annihilating photon
ocket. If some means could be found for storing large
quantities of positrons (Magnetic bottles perhaps?), or
f producing and storing anti matter (anti protons and
oositrons), energy could be made available in even
greater quantities than from the fusion reaction. Three
undred to one thousand times as much, depending upon
he type of fusion reaction used. Since the reacting
natter would be converted entirely into energy, the
preferred propulsion system would be one which used
he energy itself for producing thrust.

C. Free Radicals

One additional system seems worthy of note since it
as the potential for very high performance and because
t could become practical in the near future. This is the
ree radical system. One very interesting free radical is
nonatomic hydrogen with a potential specific impulse
f 1000 to 2000 seconds. Monatomic hydrogen can be
produced right now, but unfortunately it cannot be
tored long enough to pump it into a rocket. This seems
o eliminate it from present consideration—but not
necessarily. Perhaps it is not necessary to store it.
Suppose it is produced right in the rocket and used so
apidly that it recombines only in the thrust chamber!

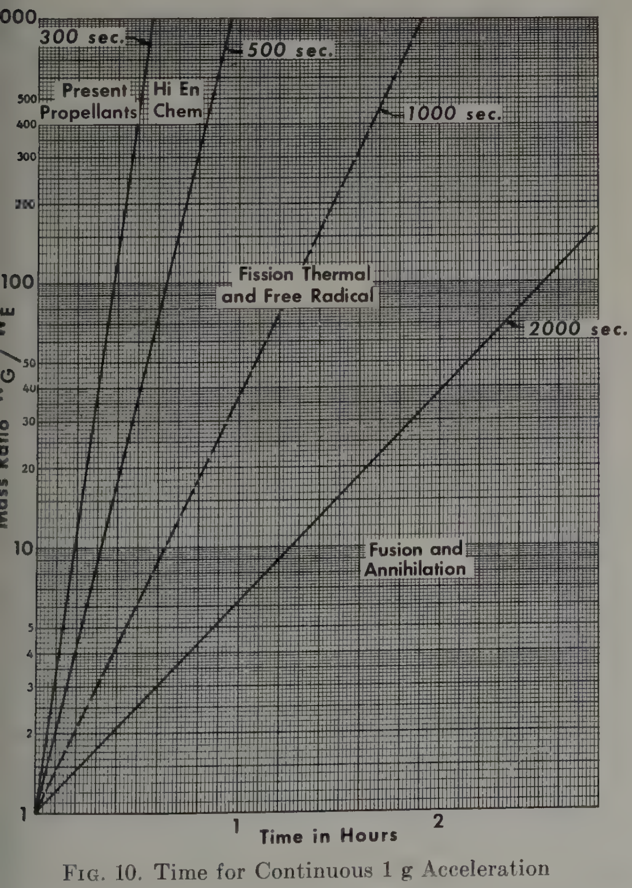

FIG. 10. Time for Continuous 1 g Acceleration

A similar device on a small scale, the atomic hydrogen cutting torch, has been in use for many years.

Some indications of the performance possibilities of future systems are presented on Figures 9 and 10. Figure 9 shows the burnout velocities attainable for various combinations of mass ratio and specific impulse. Specific impulse is the thrust in pounds obtainable from a propellant combination for every pound per second of propellant flow. The mass ratio is the initial weight of the rocket divided by the empty weight when all propellant has been expended. A mass ratio of ten is feasible for a one stage rocket. Higher mass ratios can be obtained by using multiple stages. Thus if each stage of a two stage rocket has a mass ratio of ten the overall mass ratio is the product of ten and ten or 100. A three stage rocket could thus have a mass ratio of 1000. However, for such a vehicle only one tenth of one per cent of its weight could be empty weight of the final stage and perhaps only half of this could be payload. Thus a 100,000 lb three stage rocket would have a payload of only 50 lb.

The specific impulse of present chemical propellants goes up to approximately 300 lb seconds per lb, (for vacuum conditions). High energy chemicals will go to approximately 500. If a fission reactor is used to heat a working fluid, specific impulses on the order of 1000 sec seem feasible using present techniques. Free radical systems might go to 1500 sec or beyond. Above 2000 sec ion or plasma rockets must be used with fission or fusion power sources.

Figure 10 shows how long a rocket could accelerate continuously at 1 g as dependent on its propulsion system and mass ratio. Note that a rocket with mass ratio of 1000 and a specific impulse of a little more than 1000 sec could accelerate continuously at 1 g for two and one half hours. This would be sufficient time to carry a payload to lunar impact. A specific impulse of 2000 sec would be sufficient to carry a payload at 1 g constant acceleration, to a safe landing on the moon after three and one half hours of flight.

Many other possibilities exist for developing high performance interplanetary vehicles (not all of them are rockets) but the purpose here is only to point out that there *are* many possibilities and that propulsion systems of the future will certainly not be limited to the performance of the Sputnik launchers.

Further information on advanced propulsion systems can be found elsewhere, as per example, Reference 9.

Human Factors

A. Provisions

When the interplanetary rocket is designed to carry a human crew, the time of the mission cannot be determined from consideration of the minimum energy required to propel a fixed payload, since the payload is itself a function of the time of flight.

A trip around the moon requiring only a few hours might be undertaken by one man in cramped quarters

with only the most essential equipment. On the other hand, a trip of a week or more would require large masses of provisions, which would increase the required payload and thus increase the energy requirements. It might be advisable to put this energy into reducing flight time rather than carrying the added payload. This would apply to a greater extent for trips to the planets.

B. Meteors and Cosmic Rays

Long trips will require meteor bumpers and probably cosmic ray shields. Short trips would require lighter shields or perhaps none at all.

C. Low Gravity

While there is no data indicating that selected, trained crews could not tolerate reduced or zero gravity for short periods, there are indications that long periods at low gravity might be harmful. From this standpoint the constant 1 g acceleration mission would be highly desirable.

D. High Accelerations

If it becomes possible in terms of propulsion to employ constant accelerations higher than 1 g for long periods, would crew tolerances become the limiting factor?

It appears possible that g's up to ten or even higher could be endured for long periods if the body was supported in a tank of liquid. Perhaps alternate periods of high acceleration and 1 g acceleration would be employed to reduce trip time as much as would be feasible without overstraining the crew.

From an energy standpoint, 100 g constant acceleration trips to Mars are theoretically possible. However, how the human crew could be equipped to stand such a trip is not clear. The only possibility which occurs to the writer, short of controlled gravity, is to freeze the crew solid and keep them on ice for the entire trip!

Conclusion

Consideration of human factors in space flight leads to the conclusion that the optimum transfer orbit is not that of minimum energy, even for marginal performance systems. As performance improves, the preferred orbits will diverge farther and farther away from the minimum energy orbit and toward the minimum time orbit.

Minimum time orbits, or brachistochrones, have been determined for two high thrust-to-field force cases which are: 1) departure from orbit with constant thrust greater than ten times the field force, and 2) departure from the earth's surface with thrust-to-weight ratio over ten.

In both of these cases the thrust is oriented along the outward radius.

With low thrust systems it is apparent that rate of production of energy will be a major factor in determining optimum thrust orientation. In initiating the low thrust brachistochrone from orbit it would generally be advisable to orient the thrust vector at some angle above the free fall flight path.

Some emphasis placed on minimum time orbits and the required propulsion systems should increase the economic and mission practicality of extensive travel between the planets.

References

1. Elfers, W. "Orbit Studies Using High Speed Digital Computers." Astronautics Symposium, San Diego, February 20 1957.
2. Lawden, D. F. "Transfer Between Circular Orbits." Jet Propulsion, Volume 26, July, 1956, pp 555–558.
3. Ehricke, K. "Satellite Orbits for Interplanetary Flight." Jet Propulsion, Volume 24, November–December 1954, pp 391–382.
4. Webster's Dynamics, p 77.
5. Cole, D. "The Earth-Mars Constant-Thrust Brachistochrone." Jet Propulsion, Volume 27, February 1957, pp 176–177.
6. Cole, D. "Times Required for Continuous Thrust Earth Moon Trips." Jet Propulsion, Volume 27, April 1957, pp 416–417.
7. Stuhlinger, E. "Electrical Propulsion System for Space Ships with Nuclear Power Source." The Journal of Astronautics, Winter 1955, Spring 1956, Summer 1956.
7. Spitzer, L. Jr. "Interplanetary Travel Between Satellite Orbits." Journal of the British Interplanetary Society Volume 10, 1951, p 249.
9. Zwicky, F. "Propellants for Tomorrow's Rockets." Astronautics, August 1957, p 45.

Plasma Motors*

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Abstract

It has been demonstrated that plasma consisting of titanium ions, deuterium ions, and electrons can be propelled by a small button plasma gun at speeds up to 2×10^7 cm/sec. Plasma motors employing rails should be able to obtain speeds of 10^8 cm/sec without any difficulty. The corresponding specific impulse is 10^5 sec. Several types of plasma motors will be discussed.

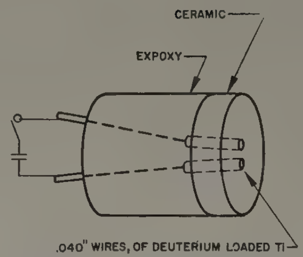


FIG. 1 Button Plasma Gun or Source

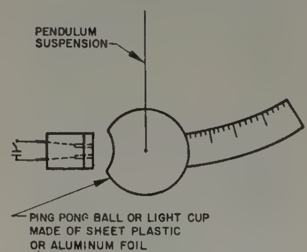


FIG. 2 Ballistic Pendulum Method for Measuring Momentum of the Plasma.

Button-Type Plasma Gun

It has been demonstrated (Refs. 1, 2, 3) that a small button probe (Figure 1) can project plasma consisting of metallic ions, deuterium ions, and electrons at speeds up to 2×10^7 cm/sec. These speeds are measured in a vacuum chamber by time of flight by means of an oscilloscope. The first-arriving plasma signal corresponds to this high speed of 2×10^7 cm/sec. There are later signals corresponding to other portions of the plasma which are traveling more slowly. However, from the predominantly positive sign of these slower signals, it can be inferred that much of this slower plasma corresponds to plasma which encountered the walls of the cylindrical vacuum chamber and thereby was slowed down.

It is necessary to devise, therefore, some method which measures the total momentum of the plasma and also the mass of the plasma. Crude ballistic pendulum measurements of the plasma momentum were made at the University of California Radiation Laboratory in Livermore in 1955 by David Finkelstein and the author. More refined measurements are now planned. The method is diagramed in Figure 2. The total momentum of the plasma will be measured by the swing of the ballistic pendulum bob which is a ping pong ball with a ½″ hole cut in it to receive the plasma. The gun, for the initial measurements, will consist of a two-wire, button-type source where the wires are made of copper. The capacitor will be discharged through the spark gap switch and permitted to ring until its energy has been dissipated, and the momentum mv of the plasma measured by the swing of the ballistic pendulum. The plasma gun and ping pong ball will each be weighed accurately. The gun will then be fired into the ping pong ball a number of times. The ping pong ball and the plasma gun will then be weighed again. The difference in the weight of the ping pong ball before and after gives the total weight of copper plasma ejected. The difference in the weight of the plasma gun before and after will serve as a check on this value. The mass m of plasma ejected per discharge of the capacitor can then be computed and since mv is already known from the ballistic pendulum method, the effective v can be calculated.

Although oscilloscope measurements show the fairly high speeds of 2×10^7 cm/sec for the first arriving plasma from the button type gun show in Figure 1 and also the coaxial (Finkelstein) gun shown in Figure 3. From the practical point of view these guns suffer from the following weaknesses:

a. The back emf (the gun is essentially a linear motor, whose armature delivers a back emf) delivered by the guns is in general small compared with the voltages which are suitable for capacitors. Consequently, the discharges of the capacitor are not anywhere near

* Presented at the IV Annual Meeting of the American Astronautical Society, New York City, January 29–31, 1958. Preprint No. 57–2.

Previously given at Conference on Advanced Propulsion, sponsored by Rocketdyne and OSR, Los Angeles, 12 Dec. 1957. This work was supported by the OSR of the Air Force and the Sherwood branch of the AEC.

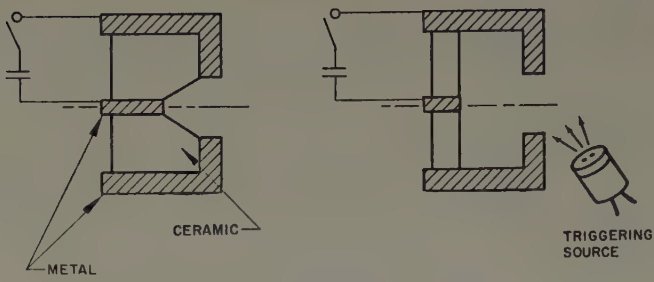


FIG. 3 Coaxial Plasma Guns

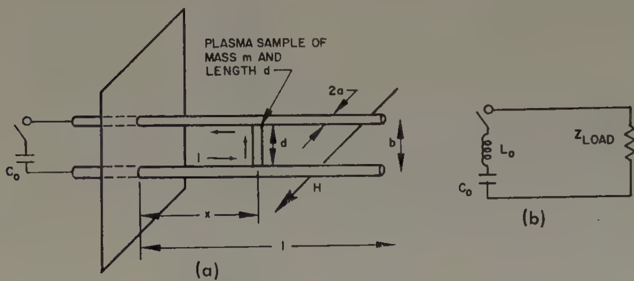


FIG. 4 (a) Rail-Type Plasma Accelerator or Gun (b) An Approximate Equivalent Circuit.

critically damped, and the capacitors ring for many cycles, thus dissipating much of their energy in circulating currents rather than storing that energy as kinetic energy of the plasma. The use of pulse transformer coupling between the capacitor and the plasma gun can improve the matching of impedances and bring about a critically damped discharge, but then the discharge time of the capacitor is correspondingly lengthened.

b. The region where the magnetic forces are concentrated and hence effective is within only a few millimeters of the gun. The time taken for a fast moving plasma ($\sim 10^7$ cm/sec) to travel this short distance is a small fraction of a microsecond. It is impractical to try to have capacitors which store reasonable amounts of energy ($\sim 10^3$ joules) discharge in this length of time. Slower capacitors cannot discharge their energy efficiently into the kinetic energy of the plasma with these kinds of guns.

c. Crude measurements indicate and theory predicts that the button source, at least, is not at all unidirectional in its plasma pattern, but fires over a fairly wide angle. For thrust purposes, only the forward momentum and energy can be utilized. This large-angle pattern of fire therefore represents a reduction in efficiency.

The system which we now propose is that of accelerating a sample of plasma by passing a current through the plasma as it rides on the rails, as indicated in Figure 4. This scheme for accelerating plasma by the current in the rails is essentially the electromagnetic gun, except that the bullet in our case is a mass of plasma or ionized gas. The analysis acceleration of a bullet by a rail system has been dealt with elsewhere (Ref. 4). Russian investigators (Ref. 5) have made a theoretical analysis of the acceleration of plasma on a rail system where an externally excited magnetic field is applied to the plasma. However, they have not considered the effect of the magnetic field due to the current in the rails. Russian investigators (Ref. 6) have also conducted experiments involving the acceleration of a plasma sample, which begins as a metallic wire, by means of rails and have achieved speeds of 10^7 cm/sec

The simple analysis that follows gives a relatively easy way of assessing the effect of various parameters in a rail-type plasma motor without the laborious task of numerical integration of the equations of motion.

The Series Plasma Motor

If, as is indicated in Figure 4, m is the mass of the plasma sample which is placed between two rails of radius a and spacing b, and if a current i flows down one rail, through the sample, and back the other rail the plasma sample is immersed in a magnetic field of value

$$H_{av} = \frac{2i}{10_b} \ln \frac{b}{a} \cong \frac{2i}{10_d} \ln \frac{b}{a}. \qquad b \cong d$$

The force on this sample is then

$$f = \frac{2i^2}{10^2} \ln \frac{b}{a}$$

The acceleration of the plasma sample is given by

$$d^2x/dt^2 = f/m = (21^2/10^2m) \ln b/a.$$

The velocity acquired by the plasma sample is

$$v = \int_0^t (d^2x/dt^2)\, dt = (2/10^2m)[\ln b/a] \int_0^t i^2\, dt$$

$$= (4.6/10^2m)[\log_{10} b/a] \int_0^t i^2\, dt$$

If we use the expression $\hat{L} = 0.92\ [\log_{10} b/a]\ 10^{-}$ henries/cm for the inductance per unit length of a two wire transmission line, where end effects have been neglected, the back emf at $x = 0$ cm be computed to b

$$V_{x=0} = \frac{d}{dt}[\hat{L}xi] = \hat{L}x\frac{di}{dt} + \hat{L}i\frac{dx}{dt},$$

where the latter term is

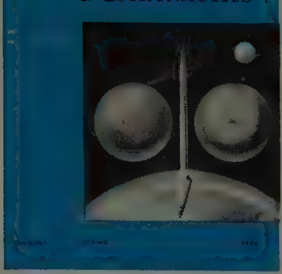
$$0.92[\log_{10} b/a]^2(4.6/10^2m)i \int_0^t i^2\, dt(10^{-8})$$

$$= (4.24/10^{10}m)[\log_{10} b/a]^2 i \int_0^t i^2\, d$$

To obtain the energy put into the transmission line at the point $x = 0$, we must evaluate the integrals

$$E_{in,x=0} = \int V_{x=0}\, i\, dt = \hat{L} \int_0^t ix \frac{di}{dt}\, dt + \int_0^t i^2 \frac{dx}{dt}\, dt$$

For a given energy source such as a capacitance C charged to V_0 volts with an inductance L_0 (internal switch, and lead inductance) in series, these integrals become unwieldy. Let us therefore make some simplifying assumptions to make the relationships more transparent. Let us assume that the current i is a constant



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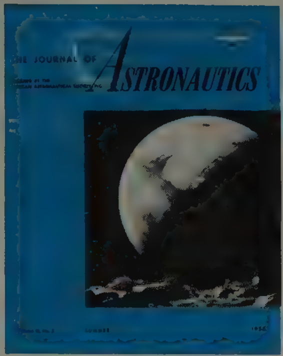

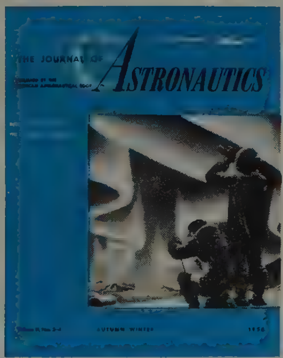

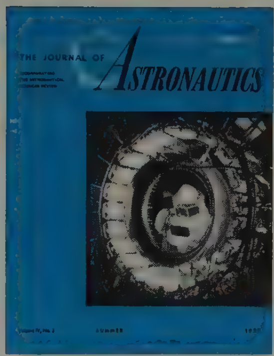

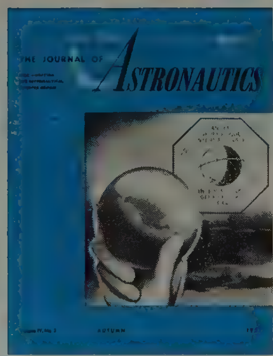

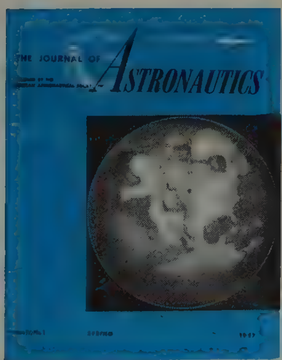

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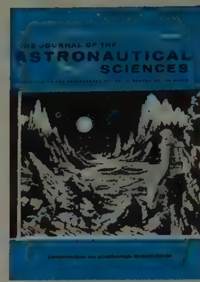

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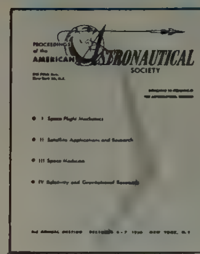

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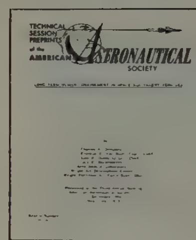

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lue I. Then

$$v = 2I^2/10^2m\left[\ln\frac{b}{a}\right]t = (4.6I^2/10^2m)\left(\log_{10}\frac{b}{a}\right)t,$$

$$V_{x=0} = \hat{L}I(dx/dt) = (4.24/10^{10}m)\left[\log_{10}\frac{b}{a}\right]^2 I^3t^2.$$

nd

$$E_{\text{in}} = \int V_{x=0}I\,dt = (2.12/10^{10}m)\left[\log_{10}\frac{b}{a}\right]^2 I^4t^2.$$

Since, as we have already indicated, the integration the equations of motion with the driving circuit, a pacitor of capacitance C_0 with internal inductance us switch and lead inductance L_0, as shown in Figure , is somewhat tedious and the results are unwieldy, t us assume that the capacitor with its internal inctance can for purposes of simplicity be replaced by battery of voltage V_0 and internal impedance

$$Z = \sqrt{\frac{L_0}{C_0}}, \quad \text{(Figure 4b)}.$$

ith the closing of the switch the relationship

$$_0 = Z_0 i + \frac{d}{dt}(\hat{L}xi) \cong Z_0 i + Z_{\text{load}}\, i \cong Z_0 I + Z_{\text{load}}\, I$$

revails where now

$$Z_{\text{load}} \cong (4.24/10^{10}m)\left[\log\frac{b}{a}\right]^2 I^2t.$$

he impedance Z_{load} may be thought of as an approxiation to the impedance of the load which consists of e two-wire transmission line and the plasma. Fairly ficient transfer (about 50%) of energy to the load curs when $Z_{\text{load}} \cong Z_0$. This energy is shared between e kinetic energy of plasma and the inductive energy ored in the two-wire transmission line. Almost comlete transfer of energy to the plasma occurs when $_{\text{load}} \gg Z_0$. Under these circumstances the back emf ue to the plasma traveling in H_{av} is sufficient to reduce e current almost to zero, and there is then very little agnetic energy left in the transmission line. In Table we have inserted some practical numbers. It can be en that with a pair of rails 50 cm long, with $b/a = 10$, current I of 10^4 amperes, a 10^{-7} gm sample can be ven a speed of 4×10^7 cm/sec. The effective plasma pedance $Z_{\text{load}} = 0.42$ ohm is fairly high and it is sy to obtain a capacitor with $C_0 = 2.4\ \mu f$, and L_0 w enough so that $Z_0 = \sqrt{L_0/C_0} \leq 0.42$ ohm.

Combination Series–Shunt Plasma Motor

An obvious step is to add an externally-excited magtic field H, as indicated in Figure 4a in order to obin the analogue of a series shunt-wound motor. The fect of such an additional shunt field H is to increase e field in which the current i in the sample is flowing that the force accelerating the sample is given by $= i(H_{\text{av}} + H)d/10$. The velocity is given by

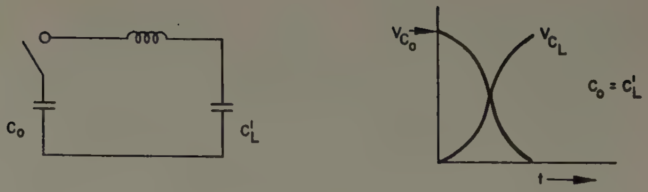

FIG. 5 An Alternative Equivalent Circuit

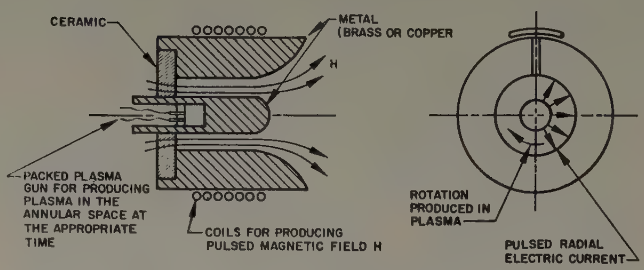

FIG. 6 Arrangement for a rotary, shunt plasma motor where the rotational velocity of the plasma ring become transformed to linear velocity v as the ring is ejected from the motor. The copper electrodes also serve as flux concentrators so that the magnetic field H can be made as high as 10^5 gauss without any great difficulties.

$$v = \int\frac{F}{m}dt \cong \frac{d}{10m}\int i\left[\frac{2i\ln b/a}{10d} + H\right]dt$$

$$= \frac{1}{10m}\int i\left[\frac{4.6i\log_{10}b/a}{10} + Hd\right]dt.$$

The back emf measured at the point $x = 0$ is

$$V_{x=0} = \hat{L}x\frac{di}{dt} + \hat{L}i\frac{dx}{dt} + \frac{Hd}{10^8}\frac{dx}{dt},$$

and the energy input at the point $x = 0$ is

$$E_{\text{in}} = \int V_{x=0}\,i\,dt = \int_0^t \hat{L}xi\frac{di}{dt}dt + \int_0^t \hat{L}i^2\frac{dx}{dt}dt + \int_0^t i\frac{Hd}{10^8}\frac{dx}{dt}dt$$

To evaluate E_{in} for a power source such as is shown in Figure 4a is a tedious task. We again make the simplification of making i equal to a constant value I. Then

$$v = 1/10m\left[\frac{2I^2\ln\frac{b}{a}}{10} + IHd\right]t$$

$$= 1/10m\left[\frac{2I^2\log\frac{b}{a}}{10} + IHd\right]t,$$

$$V_{x=0} = \left[\hat{L}I + \frac{Hd}{10^8}\right]\frac{dx}{dt}$$

$$= \left[0.92\left(\log_{10}\frac{b}{a}\right)10^{-8}I + \frac{Hd}{10^8}\right]\frac{d}{10m} \cdot \left[\frac{4.6I^2\log_{10}\frac{b}{a}}{10d} + IH\right]t,$$

and

$$E_{in} = \int V_{x=0}\, idt = \left[0.92\left(\log_{10}\frac{b}{a}\right)10^{-8}I + \frac{Hd}{10^8}\right] \cdot \frac{d}{10m}\left[\frac{4.6I^2\log_{10}\frac{b}{a}}{10d} + IH\right]\frac{It^2}{2}$$

$$V_0 \cong Z_0\, i + Z_{load}\, i \cong Z_0\, I + Z_{load}\, I,$$

where

$$Z_{load} \cong \left[0.92\left(\log_{10}\frac{b}{a}\right)10^{-8}I + \frac{Hd}{10^8}\right]\frac{d}{10m} \cdot \left[\frac{4.6I\log_{10}\frac{b}{a}}{10d} + H\right]t.$$

TABLE I

$I = 10^4, m = 6 \times 10^{16} \times 1.6 \times 10^{-24} = 10^{-7}$ grams, $d = I$, $t = 10^{-6}$ sec

	$H = 0$ (series motor)	$H = 10^4$ (series shunt motor)
v	4.6×10^7 cm/sec	1.46×10^8
l	23 cm	73 cm
$V_{x=0}$	4.24×10^3 volts	2.8×10^4
E_{in}	22 joules	140
C_0 from $E_{in} = \frac{1}{2}C_0V_0^2$	2.4 μf	.36 μf
L_0 from $\sqrt{L_0C_0} = t$	0.42×10^{-6} h	2.76×10^{-6} h
Z_{load}	0.42 Ω	2.8 Ω
Z_0	0.42 Ω	2.8 Ω

In Table I we have tabulated the appropriate values for v, l, $V_{x=0}$, E_{in} Z_{load}, C_0, and L_0 for the same values as for the series plasma motor with the value of H equal to 10^4 gauss.

If the magnetic field H_{av} due to the current in the rails is negligible compared with H, the externally applied magnetic field, it is possible to use the equivalent circuit of Figure 5, where C_0 is the storage capacitor and where the plasma is effectively the capacitance C_L into which a certain fraction of the energy of C_0 will be discharged, depending upon the ratio C'_L/C_0. If $C'_L = C_0$, or is made so by the insertion of a pulse transformer, all of the energy of C_0 can be transferred through the inductance of C'_L. The physical analogue is the complete transformation of electrostatic energy in the capacitance C_0 to kinetic energy of motion of the plasma in one-half cycle. If $C'_L = C_0$, $C'_L = 2E_{in}/V^2 = 10^9m/H^2d^2$ farad.

Presumably the most efficient way to operate the motor is to adjust the parameters so that the back emf reduces the current to zero, and hence leaves no energy stored in the transmission line, just as the plasma leaves the end of the rails. Under these circumstances all of the energy stored in the capacitor is transformed to kinetic energy of motion of the plasma, during the first half-cycle of current. Moreover, no arc will be drawn at the end of the rails as the plasma leaves because no current will be flowing.

The series and series-shunt motors diagrammed [in] Figure 4 put their energy predominantly in the forwa[rd] direction. They also are capable of developing adequa[te] back emf's. It can thus be seen that they do not suf[fer] from the same difficulties as the button sources.

Rotary Shunt Plasma Motor

A variation on the shunt plasma motor is to arran[ge] the magnetic field as shown in Figure 5. Here t[he] plasma will pick up rotational kinetic energy and t[he] duration of the application of the current can be chos[en] to be as long as one pleases. Hence, the plasma can [be] accelerated in principle to speeds which are limited o[nly] by the mechanical strength of the materials used [in] the apparatus. The rotational kinetic energy will [be] transformed to translational kinetic energy as t[he] plasma ring is propelled to the right by the gradie[nt] in the magnetic field.

Barrage of Button Guns

The matching of the impedance of the power sour[ce] can presumably be accomplished by making an arr[ay] of button sources and connecting them all in seri[es]. Although such an arrangement would seem a priori [to] be inferior to the rail type plasma motors described [in] Figure 4, it will nevertheless present some interesti[ng] phenomena involving the manner in which the in[di]vidual pieces of plasma ejected from the individual gu[ns] interact with one another.

General Comments on Efficiency

It has been shown that, in principle, it is possible [to] transfer most of the energy stored in a capacitor to [the] plasma in the form of kinetic energy. The energy [ex]pended in ionizing the gas is a small fraction of t[he] kinetic energy stored in these ions, the latter bei[ng] 5000 ev for hydrogen ions at $v = 10^8$ cm/sec. T[he] kinetic energy of metallic ions at these speeds is c[or]respondingly larger.

The specific impulse is given by v/g.

Thus for speeds of 10^8 cm/sec the specific impuls[e is] 10^5 sec.

References

1. W. H. Bostick, *Phys. Rev.* **104:** 292 (1956); **106:** 1[...] (1957).
2. W. H. Bostick and O. A. Twite, *Nature* **179:** 214, (19[57]).
3. E. Harris, R. Theus, and W. H. Bostick, *Phys. Rev.* **1**[...] 46, (1957).
4.* K. Millsaps, Holloman Air Development Center, Ope[ra]tions Research Office, Technical Memorandum No[.] "The Linear Acceleration of Large Masses by Electr[ical] Means".
5. A. I. Morozov, *Soviet JETP* **5:** 215, (1957).
6. L. Artsimovich, S. Chuvatin, S. Lukjanov, and [...] Podgorny, *Soviet JETP* **33:** 3, (1957), "Elec[tro]dynamical Acceleration of Plasma Bunches".

* The development of experimental equipment for accele[rat]ing pellets has been carried on very successfully by Mor[...] Levine at the Air Force Cambridge Research Center.

Synthesis of Human-Automatic Control Systems for High Performance Vehicles

William L. Morris, Autonetics Division, and Richard C. Kaehler, Los Angeles Division

North American Aviation, Inc., Los Angeles, California

bstract

A summary of tests conducted at North American Avia-
on, Inc. utilizing analogical computer simulation methods
ıd simulation by specially equipped aircraft in order to
tegrate optimally human pilots with automatic control
stems for high performance vehicles. The discussion in-
udes, description of missile systems, simulation methods
ıd equipment, test procedures, results and, applications to
ace systems.

Introduction

The advantages and disadvantages to be derived om the inclusion of human pilots in space vehicles have een topics of discussion for many years. Factual formation, however, regarding the actual use of ıman pilots is noticeably absent. North American viation has, through the development of the X-10 and SM-64 missile systems, accumulated test results ertinent to the integration of human pilots and flight ontrols for these missile systems. Results were obtained r analogical computer simulation as well as simulation y specially equipped aircraft. Since one of the pro- osed uses of a human pilot is to function as a con- nuously active component in a space vehicle control stem, it is the purpose of this paper to present a ımmary of these studies, including methods of simula- on and results obtained. It appears that studies of this ind offer the best approach to the synthesis of human- ıtomatic control systems for space vehicles.

I. Description of Missile Systems

The two missile systems for which composite control stems were synthesized by simulation method were ıe X-10 and the XSM-64 systems, both being separate ages in the proposed NAVAHO system.

The X-10 was turbojet powered and capable of ıpersonic speeds. It performed conventional takeoff ıd landings. The length of the aircraft was about 800 ches.

Acknowledgment: The authors express their gratitude to orth American Aviation, Inc., for permission to publish this ıper which is based on studies performed jointly by the issile Development and Autonetics Divisions of that com- ıny.

Preprint No. 57-20.

Operations were initially conducted on a dry lake bed with almost limitless facilities for landing and takeoff runs. Later operations were conducted at a base which provided a single concrete landing strip 10,000 feet long and 300 feet wide.

The missile was under continuous radio command and was tracked continuously by radar. Control was normally exercised by human control pilots stationed at permanent control stations on the ground. Each was assisted by a flight engineer who monitored turbojet performance.

The various aerodynamic and engine parameters of the missile were telemetered to the ground control stations where they were recorded and also displayed on meters to the control pilot and flight engineer. Radar track data was also displayed to the pilot.

An emergency control pilot was located in a specially equipped chase plane. He had no telemetery display of the missile parameters but was able to control by visual observation of the missile.

Takeoff and landing on the strip of restricted areal extent required the use of automatic control systems. These were normally directed by the control pilot who had to be able to assume direct control in case it appeared that a malfunction had occurred in the automatic recovery.

The XSM-64 missile is still undergoing flight tests and for that reason it will not be possible to disclose performance characteristics. It will be sufficient for our purpose to mention that it is ramjet powered and is boosted to cruise altitude and speed by a rocket engine booster. It is a heavier missile than the X-10. It is launched from a near vertical attitude and is programmed to horizontal flight. The missile flies at constant Mach number during cruise.

Recovery is effected in much the same way as the X-10 but, due to the greater speed and altitude of the XSM-64, a more complicated system is required to effect the recovery of the missile. The recovery has to be directed and monitored by the control pilot who has to be qualified to assume control in case it appears that the automatic recovery system is not functioning properly.

Control is exercised by human pilots located in ground stations along the line of flight. They are assisted by flight engineers who monitor and control the ramjet engines.

Flight parameters are telemetered from the missile to the ground stations where they are recorded and also displayed for the use of the control pilots and flight engineers.

III. Simulation Methods and Equipment

Two principal methods of simulation were employed in synthesizing the composite control system. One of these was the use of a specially equipped aircraft and the other was the use of the North American Analogical Computer Facility.

Simulator Aircraft

The simulator aircraft used were F-86D's bailed to North American for the purpose of missile simulation. They were especially equipped so as to simulate the respective missiles, one being rigged to simulate the X-10 and the other to simulate the XSM-64. The special equipment in each case consisted of an autopilot which was the near replica of the missile autopilot, radio command, and telemetery equipment. The cockpit of the X-10 simulator is shown by Fig. 1.

During all simulation flights of the simulation airplane it was occupied by a human "safety" pilot. The control system was so arranged that he could select "Remote Control" in which case another pilot either on the ground or in another aircraft could exercise control by radio; he could select "Local Control" in which case the safety pilot, himself, could control the aircraft through the missile-type autopilot; or he could override the autopilot and take direct control of the aircraft through the normal control system.

When in "Remote Control" the airplane simulated the missile by virtue of responding to radio commands from the ground controller and giving radar indications of those responses.

In operations with the simulator aircraft, the same ground stations equipment was used as was to be used in the missile operations.

The differences in performance of missile and simulator aircraft did, of course, require some changes in the simulator autopilot and in the ground equipment. In these cases, the changes were made so as to cause the simulator to perform as nearly like the missile as possible.

Analogical Computer Simulation

The simulation studies based on the electronic analog computer may be represented schematically by the block diagram in Fig. 2.

The analog computer consisted of a collection of amplifiers, servos, relays and other electric devices

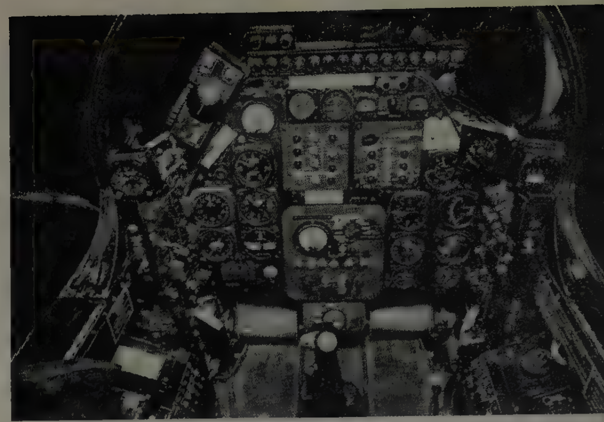

Fig. 1. Cockpit of X-10 Simulator

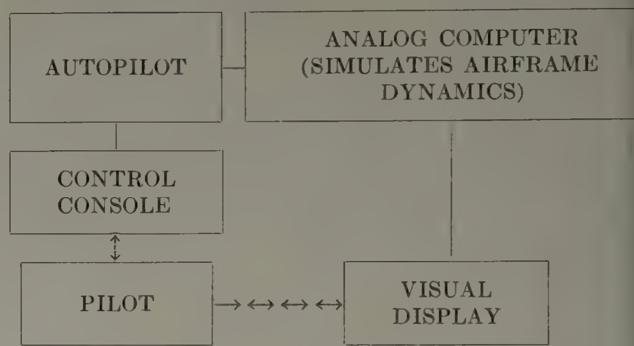

Fig. 2

which were rigged so as to solve the differential equa- tions describing the airframe behavior. In order to be a accurate as possible a duplicate autopilot was used an tied in to the computer.

The output from the computer was used to actua the same visual displays to the control pilot as it wa expected that he would have during the operation i question.

IV. Test Procedures

A total of 332 operations were made with the X-1 simulator and 168 with the XSM-64 simulator. O these flights, 155 of the X-10 simulator flights could b regarded as contributory to the synthesis of the compo ite control system, and about 28 of the flights of th XSM-64 simulator were in this category. The contr system synthesis was complete in both cases long befo the termination of the flight test programs. The subse quent flights were made to maintain the skill of th control pilots.

There were 27 analogical computer studies involve in the synthesis of the X-10 control system and the were six studies of the XSM-64 system. Eight enginee ing test pilots took part in these sessions.

Figure 3 shows a ground pilot operating the contr console to determine the extent to which boost contr could be assisted by the control pilot. The effects of h control are shown by the vertical plotter which simu lates the radar plotter used in actual operations. He operating the pitch and turn turret with his right han

he meters indicate various flight parameters. In the ckground are several of the analogical computer cks.

Figure 4 is another view of the same test which dicates the complexity of the problem. All of the uipment shown in this figure was used in this tudy.

The basic method consisted of giving control to the ntrol pilot with the simulated missile in an initial nfiguration which was likely to occur in flight and en evaluating the ability of the ground control pilot give the desired control to the missile during the suing period. In some cases, the desired control nsisted in causing the missile to attain a different nfiguration with proper timing or position. In other ses, the desired control consisted in sensing a malfunc-on of the system and taking appropriate corrective easures.

The simulator aircraft was found to be of especial lue since it was maintained at the test station and as available on a day-to-day basis. Its use had the rther advantage of the pilots using the same ground uipment as was to be used during the missile opera-on, which of course made for a greater degree of alism in the studies. One of the studies was the tomatic approach control system, where it was itially applied to evaluate the ability of the pilot to ing the missile sufficiently close to the reference glide th in order to start an automatic recovery. After the covery system had been completely developed, this udy was repeated to give the control pilots dress hearsal type experience before each missile operation.

From the systems point of view, the most important ntribution of the use of the airplane simulator was the aluation of the system performance when subjected atmospheric turbulence and stochastic disturbances other kinds.

The electronic analog computer type simulation was best value in those studies where missile performance as markedly different from that of the simulator rcraft and where accomplishing a flight test objective quired that the missile be controlled so as to have a ecified configuration at a specified place. In such case, e analogical computer was able to indicate the missile nfiguration continuously during a hypothetical ght and thus indicate whether the human pilot was le to control the missile as needed.

Due to the flexibility of the analogical computer, it as possible to simulate quite easily malfunctions of most any kind and thus to evaluate the ability of the lots to sense the malfunctions and to take remedial easures.

Results and Conclusions

Based on the end result, the simulation studies with e simulation aircraft and with the analogical com-ter simulation may be said to have been successful the X-10 and XSM-64 composite control systems ve functioned satisfactorily.

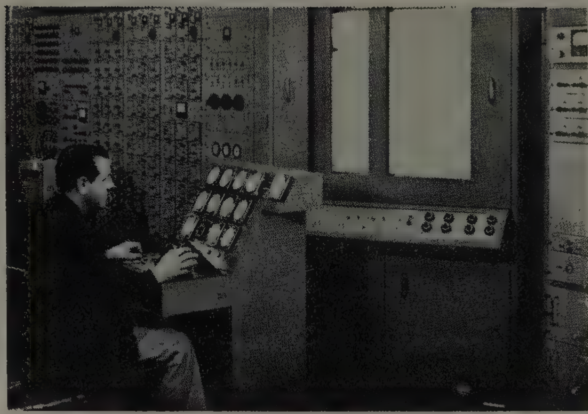

Fig. 3. Ground Pilot Operating Console

Fig. 4. View of equipment Used in Test

An analysis of missile performance indicates that a large percentage of flight attempts have been successful. Of the flight attempts which resulted in crashes, in only one case was pilot error even partly responsible. In that instance, a serious power plant malfunction caused a wide deviation from the prescribed flight plan and, during the ensuing period of attempting to return to the flight plan, the pilot failure contributed to the loss of the missile. In all other cases, missile crashes were due to component failure which were beyond the power of the pilot to correct. Of the successful flights, about 25 percent were saved at some critical control stage by the action of the human control pilot.

It is beyond the scope of this paper to discuss all the tests in detail. Certain specific conclusions indicated by the tests and various decisions based on those tests will serve to indicate the scope of the work. These are given below.

1. It was found that the control systems and the control console, as designed, were satisfactory for control of the missile by human pilots. This conclusion, which was indicated by computer studies prior to actual flight tests, was later verified by flight operations.

2. It was found that the X-10 could be landed under airborne control. It was found that the best gear ratio for the pitch controller in this application varied with the individual. The particular pilot scheduled to control the X-10 during its first landing preferred a 6:1 gear

ratio, i.e., six degrees of shaft rotation to one degree of pitch command and the airborne control system was setup on that basis. A gear ratio of 15:1 was found to be more generally suitable, and hence the ground console pitch controllers were built with that ratio.

3. It was found that pilots could control the X-10 so as to attain the proper Mach number at the proper altitude at the proper geographical locations to execute a vertical dive-in.

4. It was found that ground control pilots were able to sense most of the malfunctions likely to occur in the automatic landing system in time to execute a waveoff, and thus would be able to recover a turbojet powered missile.

5. It was found that pilots were unable to stabilize the missile to within 100 yards laterally or 100 feet vertically of the glide path as required by the originally proposed automatic recovery system. On a basis of this conclusion, the control system was changed to one which could be initiated by human pilots.

6. It was found that human pilots were unable to sense malfunctions in the XSM-64 boost control system in time to make a suitable correction. Consequently pilots were instructed to make no pitch or lateral control corrections during boost and reliance on the automatic control system during these phases of control was made complete.

7. It was found that human pilots could control the missile during the approach phase with sufficient accuracy up to about the time of automatic landing flare, provided accurate radar information were available.

8. It was found that control of a missile could be shifted from one control station to another by voice coordination with no difficulty.

9. It was found that a "Hold Altitude" control mode was unsatisfactory for deceleration preparatory to entering the automatic approach control system, but that human pilots could handle the deceleration satisfactorily with the control system in "Manual Pitch Control" even while executing lateral maneuvers.

10. It was found that X-10 take-offs could be made by commanding a fixed pitch attitude until lift-off, then commanding a few degrees higher pitch attitude. This was held until landing gear was retracted. Thereafter, the missile was in an airborne configuration and could be maneuvered in accordance with the flight plan.

11. It was found that human pilots could control a ramjet vehicle so as to maintain Mach number in the event that the automatic Mach control system failed.

12. It was found advisable to change vertical radar plotting scales from 1:62500 to 1:125,000 in range, and to retain a scale of 1:62,500 in altitude so that the initial control phase could be contained on one continuous plot.

13. It was found advisable to display time during boost phase to the control pilots in order to monitor time sequenced events. The form was a single hand clock making one revolution during the period of boost.

14. It was found advisable to display normal accele tion to the pilots, because it gives a more rapid indi tion of control system malfunction than related para eters.

15. It was found that a satisfactory sequence making automatic recoveries could be devised REAC simulation.

16. It was found that a complete series of structu integrity tests could be completed by the human pi within time and space requirements imposed by ra and flight plan.

VI. Applications to Space Systems

The extension of the methods described herein space systems, such as satelloids, is reasonably dire especially in the critical control phases of launch a recovery. Satellite cruise should also be capable quite close simulation insofar as the control system concerned. In these phases, analogical comput simulation of the vehicle would proceed as with t missile system described above. It appears, in fact, th an adequate control system can be most easily attain by this means. Some of the specific problems which a capable of solution in this way are:

1. The basic question of which controls should automatic and which should be performed by the pil
2. The flight parameters which should be displayed the pilot and the most effective means of display.
3. The type of controls best suited to use by a hum pilot.
4. Detailed procedures to be used in each phase flight.
5. Emergency procedures to be followed in case malfunction of equipment.

While considerable disparity exists between t performance of currently operational aircraft and th of satelloids, it, nonetheless, appears that considera value may be derived from the simulation of the lat part of reentry and of the recovery phase by the use o properly rigged aircraft. The basic information to gained from this type study comprises the following:

1. Suitability of ground system.
2. Effect of noise and random disturbances on pi performance.
3. Ability of pilot to recover aircraft using a propos recovery system.

As a closing remark, the overall results of the studies have shown that a human pilot acting as continuously active component in the control syste whether he is airborne or on the ground, will grea increase the probability of successful flight as long as is given the proper instruments and controls by whi to detect and correct for malfunctions.

The tests conducted by this organization to da indicate that a man's ability to exercise *judgement* is central importance in a flight control system for a but the most simple space vehicle. At the present st of the art, this judgment can not be exercised electronic means.

NEWS OF THE AAS

Annual AAS Meeting in Washington, D. C.

The fifth annual meeting of the Society will be held in ıjunction with the 125th Annual Meeting of the American sociation for the Advancement of Science in Washington, C. The sessions will be held in the Congressional Room of e Statler Hotel, December 27 to 30, 1958.

The tentative program includes:

Saturday, 27 December 1958

orning (Session I)
:30–9:30: Registration
:00–10:30: Presidential Welcoming Address
:30–12:00: Guest Lecture
ternoon (Session II)
.M.: Man's Environment in Space
ening
nor's Night Dinner

Sunday, 28 December 1958

orning
(none)
ternoon (Session III)
.M.: Upper Atmosphere Research
ening
ard of Directors Meeting

Monday, 29 December 1958

orning (Session IV)
.M.: Space Vehicle Design
ternoon (Session V)
.M.: IGY Rockets and Satellites (AAS is a co-sponsor for s IGY Session)
ening
siness Meeting

Tuesday, 30 December 1958

rning (Session VI)
.M.: Guidance, Control and Communications
ernoon (Session VII)
.M.: Lunar Explorations

Titles and Abstracts of technical papers to be presented at V Annual Meeting in December 1958 of the American ronautical Society are invited. Tentative topics are shown the program outline. Please submit manuscripts with strations to:

Professor Frederick V. Pohle
Polytechnic Institute of Brooklyn
333 Jay Street
Brooklyn 1, New York

gram Chairman: Ross Fleisig, President AAS, Sperry Gyroscope Company, Great Neck, New York.
hnical Sessions Chairman: Professor Frederick V. Pohle
hnical Papers Committee Chairman: Dr. Horace Jacobs, Lockheed Missile Systems Division, Palo Alto, California.
Regional Section Host: Washington D. C. Area Section, *John Crone*, Chairman, 3522 Nimitz Rd., Kensington, Maryland.

Preprints and complete proceedings will be made available to meeting participants.

Fig. 1. Initial check for corporate membership on behalf of Sperry Gyroscope Company is presented by *Dr. W. L. Barrow*, research vice president (right) and Air Armament manager *Herbert Harris* (left) to *Ross Fleisig*, society's president and also Sperry engineering section head for astronautics.

Society Becomes an Affiliate of AAAS

The Board of Directors is pleased to inform the membership that the society has become an affiliate of the American Association for the Advancement of Science. Dr. Dael Wolfle, AAAS Executive Officer, announced this affiliation at the IV Annual Meeting Honors Night Dinner.

For the information of those members who may not be familiar with AAAS, these facts may be of interest:

(1) AAAS, which was incorporated in 1874, exists: to further the work of scientists, to facilitate cooperation among scientists, to improve the effectiveness of science in the promotion of human welfare, and to increase public understanding and appreciation of the importance and promise of the methods of science in human progress.
(2) AAAS, which is a non-profit scientific and educational body, has 56,000 individual members and 279 affiliated scientific societies, academies, and other professional organizations.
(3) AAAS has 18 sections corresponding to the major branches of sciences. These sections serve as a basis for organizing programs of interest to members. AAS has designated its interest in the Physics, Engineering, and Medical Sciences sections.
(4) AAAS publishes the journal, SCIENCE, weekly. The April 25th issue carried an article written by AAS

President Ross Fleisig in which the AAS aims, technical programs, publications, and related information were presented.

(5) AAAS' Annual Meeting will be held on 26–31 December 1958 in Washington. This year AAS will have its V Annual Meeting in conjunction with the AAAS function.

(6) AAAS' advisory and legislative body is the Council. The 1958 Council representative for AAS is Paul A. Campbell of the U.S. Air Force School of Aviation Medicine.

Further information regarding the association may be obtained from: American Association for the Advancement of Science, 1515 Massachusetts Avenue, N.W., Washington 5, D. C.

New Corporate Members of Society

Five American industrial organizations have joined the Society recently. Included in this group are: *Republic Aviation Corporation*, *Specialized Propulsion and Control Equipment (SPACE) Corporation*, *Kearfott Company Inc.*, *The Martin Company*, and *Sperry Gyroscope Company*.

Named as principal contacts between these organizations and AAS are the following:

Mr. Alexander Kartveli, Vice-President—Research and Development of Republic Aviation Corporation.

Mr. M. G. Hughett, President of SPACE Corp.

Mr. D. Balber, Head, Engineering Technical Office of Kearfott Company Inc.

Mr. George S. Trimble, Vice President—Engineering of The Martin Company.

Dr. W. L. Barrow, Vice President for Research and Development of Sperry Gyroscope Company.

The Society welcomes these companies as Corporate Members and acknowledges their support of AAS toward the development of the astronautical sciences in the United States.

IX IAF Congress Papers

The ninth Annual Congress of the International Astronautical Federation was held in Amsterdam, The Netherlands during the week of August 25 to 30, 1958. Nederlandse Vereniging voor Ruimtevaart was the host society.

Approximately 60 technical papers dealing with many fields in the astronautical sciences were presented. Several papers, given by AAS FELLOWS and MEMBERS, were as follows:

1. Astronautics and Astronomy by Professor George Gamow.
2. The Supersonic Flow About a Blunt Body of Revolution for Gases at Chemical Equilibrium by F. G. Gravalos, P. H. Edelfelt and H. Emmons.
3. Consideration of the Solar Probe by R. P. Haviland.
4. On the Development of Orbital Techniques by H. H. Koelle.
5. General Variational Theory of the Flight Paths of Rocket-Powered Aircraft, Missiles and Satellites by Prof. Angelo Miele.
6. Principles of Inertial Control of Satellite Attitude by R. E. Roberson.
7. An Interplanetary Navigation Plan by E. V. Stearns.
8. Explorer by Dr. Wernher von Braun.

In addition papers were delivered by Dr. Jakob Ackeret of Switzerland, Dr. J. M. J. Kooy of The Netherlands, Dr. Alla Massevitch of U.S.S.R., Dr. Eugene Sanger and Dr. Irene Sanger-Bredt of West Germany, Dr. L. R. Shepherd of England, Prof. E. Vassy of France, and Dr. Theodore von Karman and Dr. Fred Whipple (AAS Fellow) of the U.S.

San Francisco Peninsula Section News

At a recent meeting of the San Francisco Peninsula Sectio held at Stanford University and attended by 150 to 2 people, papers on future propulsion systems were present by Mr. John Gustavson of the University of Californ Berkeley and by Dr. Sidney W. Kash of Lockheed Miss Systems Division. The speakers indicated that there we many possibilities for future propulsion systems but that mu needed to be accomplished both in theory and developme before practical application could be made of these systen Abstracts of these papers follow.

Advanced Propulsion systems, John Gustavson. A discussi of propulsion systems of the present day and those of t future were discussed. Existing systems were examined a the expected limits for these were reviewed. A rather bro treatment of free radicals, nuclear rockets, solar power systems, plasma jets, and ionic rockets was presented.

Sydney W. Kash

Hydromagnetic Propulsion, Sydney W. Kash. This ta described the essential features and limitations of propos electrical schemes for propulsion. Interest in such machin stems from their ability to eject propellants with a high specific impulse than obtainable with chemical rocket moto In addition to the plasma jet, ion gun, and fusion system, t discussion included a description of a hydromagnetic gun, which magnetic forces are used to obtain thrust.

In the absence of a successful fusion machine the mo likely systems are the ion gun and the hydromagnetic gu The plasma jet is not likely to be used because of inadequa specific impulse. Because of the low thrust available from t electrical propulsion devices it is anticipated that they wou be used to supplement a chemical propellant system.

The feasibility of an ion or hydromagnetic propulsion sy tem is dependent upon the development of satisfacto light-weight power plants. Since, for a fixed thrust, the pow required increases with propellent velocity, the optimu specific impulse for any given electrical system will depe upon the ratio of power plant weight to useful power outp

JOHN GUSTAVSON

uthwest Regional Section

The Society is pleased to announce that a provisional arter has been granted to the Southwest Regional ction of AAS. This Section was formed under the guidance Society Director-at-Large Austin N. Stanton. Since its mation and recognition, the Section has held several meet-s in the Dallas-Ft. Worth area. The officers of the new ction are Chairman, Prentiss Selby, Bell Heliocopter Corp., e Chairman, Claude B. Elam, Convair, Secretary, Ray ape, Intercontinental Mfg. Corp., Treasurer, Philip J. anlon, P. J. Scanlon Company. Directors are Larry E. ffman, Bell Frank, C. Seay, Jr., Collins Radio, Robert G. ch, Texas Instruments, Dr. A. R. Teasdale, Temco and le Fuller, Varo Mfg. Company.

w York Section Announces 1958 Election Results

Upon completion of the counting and certification of the ults of the ballots of Members of the New York Section for annual election of officers early in May, the Official Bal-ting Committee advised of the election of the following cers and directors: (*re-elected; company affiliations in ckets).

airman: * H. E. Weihmiller, (Republic Aviation Corp.)

ce Chairman: * Dr. C. J. Mundo, (ARMA Div., American Bosch Arma Corp.)

cretary: Edwyn A. Eddy, (Guided Missiles Div., Republic Aviation)

easurer: * Michael Marchese, (Gibbs & Cox, Inc.)

rectors At Large: John W. Lazur, (Allen B. DuMont Laboratories), * Dr. Maurice J. Kirby, (Sperry Gyroscope Co.), Gilbert E. Pinkham, (Sperry Gyroscope Co.), *Lawrence Slote, (Research Div., New York University) E. King Stodola, (Reeves Instrument Co.)

Two major appointments were also announced following election: Mr. Thomas E. Garrigan (Sperry Gyroscope .) as Chairman of the Publicity Committee, and Mr. ank S. Markil, (Guided Missiles Div., Republic Aviation rp.) as Chairman of the Special Projects Committee (in-ding the Section's MOONWATCH planning). Several ditional appointments, now pending, will be announced in ure issues of the JOURNAL.

Col. Campbell Speaks at New York Section Meeting

The New York Section of the American Astronautical Society held a General Membership meeting on Thursday, March 6 in the auditorium of the Stewart Avenue School, Garden City, Long Island. The speaker was Colonel Paul A. Campbell, U. S. Air Force, who spoke on "Human Considerations In Space Flight". Col. Campbell is Staff Assistant for Medical Research to General Gregory, the Commanding Officer of the Office of Scientific Research.

Col. Campbell outlined the basic problems of very high altitude and free flight realms, particularly in regard to the human factors, and summarized progress to date in preparation for successful space flights of the near future. Subjects ranged through the complete spectrum and included excellent comments on such aspects as weightlessness, psychological aspects and the vital need for proper orientation. His address was well illustrated by very informative colored slides.

Following the address, the audience participated through a question period. From their lively interest and variety of pertinent queries, it was apparent that those present appreciated the importance and timeliness of the subject. The Section Chairman, H. E. Weihmiller, invited Col. Campbell to consider a return engagement at an early date.

Format of Technical Papers for AAS Meetings

At the suggestion of various members of the Society the Technical Papers Committee Chairman, *Dr. Horace Jacobs*, has prepared a sample sheet of the basic requirements for technical papers to be submitted for possible inclusion in various AAS meetings. This is reproduced at this time for wide distribution. Abstracts of such communications should be typed single-spaced in a text width of 4.5 inches centered below the title and author(s) of the paper. The abstract can be brief and should not exceed 300 words in length.

1. *Introduction.* A technical paper for publication in the AAS Proceedings should be typed on a good quality bond, $8\frac{1}{2}$ x 11 inches. Except for the abstract, page width is $6\frac{1}{2}$ inches and page length is 9 inches. Copy should be typed in standard elite, preferably on an electric typewriter, and should be suitable for offset. Corrections should be stripped in rather than erased. Text is single-space with double-space between headings, equations, items, and paragraphs. Major heads are all caps and flush left.
2. *Other Main Headings.* The paper can be divided into principal sections as appropriate. Headings or paragraphs are not numbered. Secondary headings are in caps and lower case; they are flush left and underlined.
   a. *Equations.* Equations are as follows:

$$(a^2m_0/at_2^2)(a^2m_0/as_2^2) = 0 \qquad (1)$$

   Slashes should be used to separate numerator and denominator if it is conveniently possible. Equations are referenced in the text as equation (1), (2), etc.

   b. *Symbols.* Slashes are also preferred to separate numerator and denominator in the text: $m_i = m_0 \exp(-v_i/c)$. Where superscripts and subscripts make single-space typing impractical, the lines where they occur can be typed in space-and-a-half or in double-space.

   c. *Greek Symbols.* If tertiary headings are necessary they are flush left, upper and lower case, and underlined; text is run-in. Greek symbols can be prepared in one of the following ways:
   (1) Typed by varitype
   (2) Typed by a mathematical typewriter
   (3) Hand-drawn. If this method is used the following should be noted: Use black or red ink, Draw symbols neatly.

Book Reviews

The Realities of Space Travel, Edited by L. J. Carter, A.C.I.S. Putnam, London, 1957.

With the realization that several tangible earth satellites are now spinning in their orbits, this book represents a timely source of background for both the astronaut and the person newly awakened to the possibilities and problems of space travel. Although all the material in the book has been published previously since it is a collection of papers of the British Interplanetary Society, the collection of these papers under a single cover represents a definite service to the astronautical sciences.

The material has been neatly divided into headings including an Introduction to Astronautics, The Satellite Vehicle, Interplanetary Flight, Physical Factors in Space Flight, Biological Aspects, Targets for Tomorrow, and four shorter additional sections on historical factors, testing and speculations on the future.

Rather than list the principal contributors and slight someone not listed, it is sufficient to say the authors are those one would expect to find in a collection of this type.

The material is well presented and although well known to the seasoned astronaut, it will serve him well as a ready reference. For those who are technically inclined but less acquainted with the field, the book represents an excellent starter either to whet an appetite for further investigation in a specialty or as a comprehensive survey of the diverse disciplines covered.

Each article contains an adequate bibliography to permit further reading and, in addition, the editor has taken pains to relate the associated articles within their respective texts where applicable. This further enhances the cohesiveness of the collection.

G. R. Arthur
Radio Corporation of America

Satellites and Spaceflight, Eric Burgess, Macmillan Company, New York, New York, 1957, 160 Pages, Price $2.95

This book is tailor-made for the man who wants to know the why, the how, and the present status of Space Flight.

Actual photographs of the earth from flying missiles are given with detailed explanatory notes. Charts, diagrams and tables are comprehensively explained and well documented.

For those who are interested in checking details concerning particular items, Mr. Burgess has provided an index. He also utilizes numbered references in his text with listings at the end of each Chapter. Familiar names of other pioneers in the field, such as R. G. Goddard, Wernher von Braun, A. C. Clarke, and Krafft A. Ehricke appear in these extensive references.

The author presents to the reader a logical progression of events, beginning with the many aspects of an operational earth satellite and culminating with an organized space flight program for the universe. Phases of space flight concerning Instrumented Satellites, Space Stations, Lunar Colonies and Interplanetary flights are covered in great detail.

Of particular interest to those of the medical profession is Mr. Burgess' treatment of physiological as well as psychological factors (known and postulated) regarding human existence in space stations. He covers the areas of getting man into space and back, as well as how man can live once he is there.

This is an excellent reference text from which concentrated study may be launched into the particular area of concern. It is not for the neophyte, but rather for the man who has already figuratively had his first "flight into the blue" concerning the complexities of interplanetary space flight.

Major O. Frank Kattwinkel
Ballistic Missile Officer, USAF

News of the AAS

(*Continued from page 49*)

Above is an example of format for enumerations. They are indented 5 spaces.

d. *Tables*. Table headings are centered above the table and have the following format:

Table I

THE HEADING IN ALL CAPS

e. *Figures*. Line drawings suitable for reproduction may be inserted by the author at appropriate places in the text. If this is done, figures should be reduced consistent with clarity and space conservation. Captions are centered below the figure and have the following format:

Fig. 1 The Caption of the Figure

References to figures are made in the text by the designation Fig. 1, Fig. 2, etc.

If line drawings are not inserted in the text they should be provided as original artwork or photostats suitable for reproduction. Glossy black and white prints should be provided for half-tone photographs. Each figure should be numbered and a caption provided.

f. *References and Footnotes*. References listed at the end of the paper are indicated in the text by a superscript Arabic number[1]. Footnotes are called out in the text by superscript symbols *, **, †, ‡, etc. Standard practice footnotes and references are acceptable.

3. *Conclusion*. The AAS would appreciate it if each author would provide the Society with at least 100 preprints of his technical paper before the beginning of the session. These preprints should be presented in the format indicated above. However, illustrations might be interspersed in the text or placed at the end of the paper.

4. *References*.

1. C. S. Draper, Education in the Astronautical Sciences, *J. Astronautics*, Vol. IV, No. 2, pp 29–30, 1957

PROCEEDINGS
IV ANNUAL MEETING

AAS

57-1 A SURVEY OF PROPULSION AND SPACE DYNAMICS, by D. B. Cross and Jorgen Jensen, The Martin Co., Baltimore, Md.

57-2 PLASMA MOTORS, by Winston H. Bostick, Stevens Institute of Technology, Hoboken, N. J.

57-3 BERYLLIUM: PROMISING METAL OF THE SPACE AGE, by R. E. Foster and L. A. Riedinger, Lockheed Missile Systems Div., Palo Alto, Calif.

57-4 RETURNING ALIVE FROM SPACE, by Fred Riddell and R. W. Detra, Avco Research Laboratories, Everett, Mass.

57-5 SUPERSONIC FLOW ABOUT BLUNT BODIES OF REVOLUTION, by Fausto Gravalos, Missile and Ordnance Systems Department, General Electric Company, Philadelphia, Pa.

57-6 OPTIMUM THRUST PROGRAMMING ALONG ARBITRARILY INCLINED RECTILINEAR PATHS, by Angelo Miele and Carlos R. Cavoti, Purdue University, Lafayette, Indiana.

57-7 OPTIMUM BURNING PROGRAM AS RELATED TO AERODYNAMIC HEATING FOR A MISSILE TRAVERSING THE EARTH'S ATMOSPHERE, by Angelo Miele, Purdue University, Lafayette, Ind.

57-23 AN UNIVERSAL RADIO ASTRONOMY SYSTEM FOR RADIO TELESCOPES, SPACE VEHICLE TRACKING AND SCATTER PROPAGATION STUDIES, by George J. Doundoulakis, Electronics Div., General Bronze Corp., Garden City, N. Y.

57-24 R. F. PROPAGATION IN INTERPLANETARY COMMUNICATIONS, by Allen M. Peterson, Electronics Research Laboratory, Stanford University, Palo Alto, Calif.

57-25 TELEVISION TELEMETER FOR MISSILE TEST PROGRAMS, by D. Hochman and J. P. Taylor, Telecommunications Dept., Lockheed Missile Systems Div., Palo Alto, California.

57-26 DATA LINKS IN SPACE EXPLORATION - THEIR NATURE, APPLICATIONS AND LIMITATIONS, by Henry E. Prew, Aeronautical Equipment Div., Sperry Gyroscope Co., Great Neck, N. Y.

57-27 MEASUREMENT OF VELOCITY IN SPACE, by David Sonnabend, Lockheed Missile Systems Div., Palo Alto, Calif.

57-28 ELECTRONIC TECHNIQUES IN THE SOVIET UNION, by Charles L. Rouault, Heavy Military Electronic Equipment Dept., Defense Electronics Div., General Electric Co., Syracuse, N. Y.

57-9 FUNDAMENTALS OF INERTIAL GUIDANCE AND NAVIGATION, by William E. Frye, Guidance and Communications Dept., Lockheed Missile Systems Div., Palo Alto, Calif.

57-10 DETERMINATION OF AN UNIQUE ATTITUDE FOR AN EARTH SATELLITE, by William R. Davis, Lockheed Missile Systems Div., Palo Alto, Calif.

57-11 SATELLITE ASCENT VEHICLE GUIDANCE REQUIREMENTS, by C. L. Keller, Weapons Systems Engineering Dept., Sperry Gyroscope Co., Great Neck, N. Y.

57-12 INERTIAL AIDS FOR SPACE TRAVEL, by Charles Mundo, Arma Div., American Bosch Arma Corp., Garden City, N. Y.

57-29 APPROACHES TO THE DEVELOPMENT OF SPACE VEHICLES, by George W. Hoover, Commander, Office of Naval Research, USN, Washington, D.C.

57-30 SPACE CABIN DESIGN, by Al M. Mayo, El Segundo Div., Douglas Aircraft Co., El Segundo, Calif.

57-31 HYDROGEN PEROXIDE AS A SOURCE FOR OXYGEN, WATER, HEAT AND POWER FOR SPACE TRAVEL, by Noah S. Davis, Becco Chemical Co., Food Machinery Corp., Buffalo, N. Y.

57-32 A RECOVERABLE EMULSION PACKAGE FOR EXTRA ATMOSPHERIC STUDY OF COSMIC RAYS, by Robert A. Webster, The Martin Co., Baltimore, Md.

57-33 PREDICTION OF CRATERING BY METEOR IMPACTS, by Maury Kornhauser, Missile & Ordnance Systems Dept., General Electric Co., Philadelphia, Pa.

57-14 STEERING OF AN ASCENT ROCKET FOR MAXIMUM CUTOFF VELOCITY, by W. H. Foy, Jr., The Martin Co., Baltimore, Md.

57-15 ADVANCES IN ASTRO BIOLOGY, by Hubertus O. Strughold, School of Aviation Medicine, Randolph Field, Texas.

57-16 THE SELECTION AND TRAINING OF A BIO-SATELLITE CREW, by D. W Conover, E. G. Aiken, C. M. Whitlock; Convair, San Diego, Calif.

57-17 ORIENTATION OF RESEARCH NEEDS ASSOCIATED WITH ENVIRONMENT OF CLOSED SPACES, by William T. Ingram, New York University, New York, N. Y.

57-18 RADIATION DOSAGE FROM X- AND BETA-RAYS IN FLIGHT THROUGH AURORAL DISPLAYS, by Herman J. Schaefer, School of Aviation Medicine, Naval Air Station, Pensacola, Fla.

57-19 RESEARCH IN HUMAN TRAVEL ON THE ENDLESS FRONTIER OF TIME, by Charles Dempsey; Franklin D. Van Wart, Capt. USAF; Leonard Eisen, Lt. USAF; John G. Roth, Capt. USAF (MC); Nina K. Morrison, Capt. USAF; Charles Myers; Aero Medical Laboratory, Wright-Patterson Air Force Base, Ohio.

57-20 SYNTHESIS OF HUMAN-AUTOMATIC CONTROL SYSTEMS FOR HIGH PERFORMANCE VEHICLES, by William L. Morris, Autonetics Div; Richard C. Kaehler, Los Angeles Div., North American Aviation, Inc.

57-21 ISOLATION AND CONFINEMENT IN SPACE FLIGHT, by G. E. Ruff, Capt. USAF; E. Z. Levy, Capt. USAF; V. H. Thaler, Capt. USAF; Aero Medical Laboratory, Wright Air Development Center, Ohio.

57-22 DESIGN OF AN ALGAL CULTURE CHAMBER ADAPTABLE TO A SPACE SHIP CABIN, by James G. Gaume, M.D., The Martin Co., Denver, Colo.

57-35 ON THE GENERATION OF TEMPERATURES TO 30,000°K, by Peter E. Glaser, Arthur D. Little Co., Cambridge, Mass.

57-36 CONSIDERATIONS ABOUT VISIBILITY OF SATELLITES FOR THE UNAIDED EYE, by Ingeborg Schmidt, Indiana University, Bloomington, Ind.

57-39 MINIMUM TIME INTERPLANETARY ORBITS, by Dandridge M. Cole, Advanced Systems Requirements, The Martin Co., Denver, Colo.

57-40 INTERPLANETARY APPLICATIONS OF AUTOMATIC NAVIGATION, by E. V. Stearns, Lockheed Missile Systems Div., Palo Alto, Calif.

57-41 LABORATORY SIMULATION OF SPACE FLIGHT CONDITIONS, by T. C. Helvey, The Martin Co., Orlando, Fla.

57-42 PLASTIC BALLOONS FOR PLANETARY RESEARCH, by Malcolm D. Ross, Office of Naval Research, USN, Washington, D.C.

57-43 PROJECT SKYBALL: A PROPOSED PRIMARY SATELLITE TRAINER SYSTEM FOR SPACE FLIGHT OPERATIONS, by Norman V. Petersen, Lockheed Missile Systems Division, Palo Alto, California.

57-44 A PRELIMINARY DETERMINATION OF THE POSITION OF SOME FIRST AND SECOND MAGNITUDE STARS ON MARS' CELESTIAL SPHERE, by Frederick R. West, Jr., Avco Mfg. Co., Lawrence, Mass.

57-45 ON PLASMA PROPULSION, by Yusuf A. Yoler, Missile and Ordnance Systems Department, General Electric Co., Philadelphia, Pa.

57-46 THE USE OF PLANETARY ATMOSPHERES FOR PROPULSION, by Serge T. Demetriades and Carl B. Kretschmer, Aerojet General Corp., Azusa, California.

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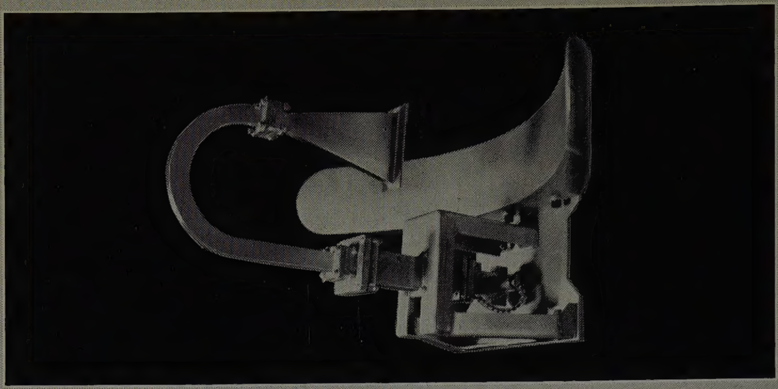
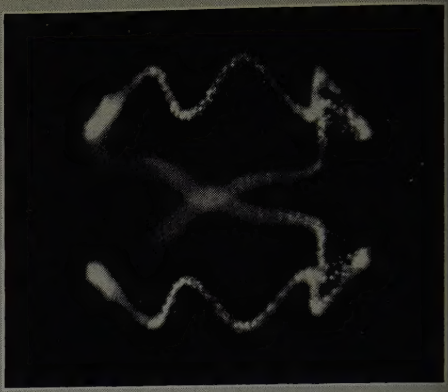
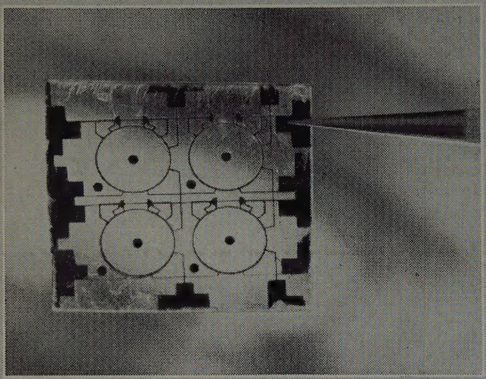


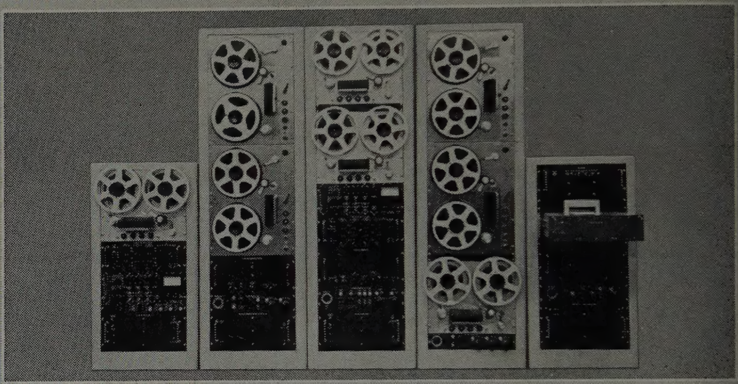
Horn fed parabolic reflector antenna for airborne applications.



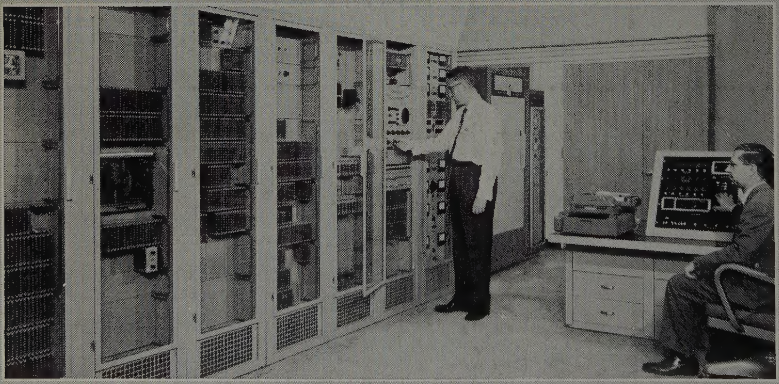
Charged aluminum particle suspended and controlled in a vacuum chamber by an oscillating electric field.



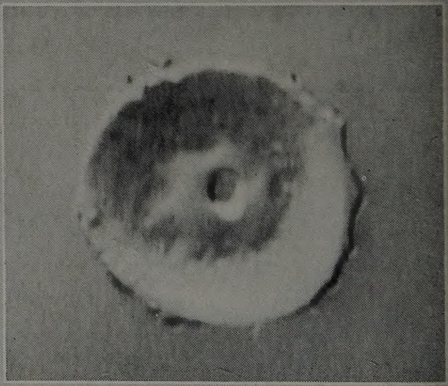
The Persistor gives promise of cryogenic computer memories with a capacity of 1,000,000 bits per cubic foot and access times of 1/30 microsecond.



Ground based data handling equipment for processing analog and digital reconnaissance information.



Data conversion system for digitizing and processing telemetered missile test data.



Electron micrograph of impact produced on aluminum coated glass by a 1 micron diameter particle traveling at 7,000 feet per second.

Pictorial **PROGRESS REPORT**

The photographs above illustrate some of the recent research, development, and manufacturing activities at Ramo-Wooldridge. Work is in progress on a wide variety of projects, and positions are available for scientists and engineers in the following fields:

- Digital Computers and Control Systems
- Communications and Navigation Systems
- Guided Missile Research and Development
- Infrared Systems
- Electronic Countermeasures
- Electronic Instrumentation and Test Equipment
- Basic Electronic and Aeronautical Research

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